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ELECTRONIC SCANNING TECHNIQUES FOR PARAMETRIC
TRANSMITTERS

Robert L. White

Texas University at Austin

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Annual Report Under Contract N00014-70-A-0166, Task 0008
1 December 1972 - 30 September 1973

OFFICE OF NAVAL RESEARCH
Contract N00014-70-A-0166, Task 0008
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ABSTRACT

A study was conducted to investigate four scanning techniques for forming multiple parametric beams in high resolution parametric sonar systems. A coded pulse scan technique employing coded pulse sequences for azimuth sector identification was found to be best suited for this application. A system was designed, constructed, and used to demonstrate the electronic scanning of a parametric beam. A nominal 2.3° beam was steered at angles of $\pm 1^\circ$, $\pm 7^\circ$, and $\pm 14^\circ$. The source level was 181 dB re 1 μPa at 1 m.

The system developed will be further employed to evaluate word sets to be used in coded pulse parametric transmitters.

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I. INTRODUCTION

The formation of a difference frequency (parametric) acoustic beam from the transmission of two beams having different frequencies has been demonstrated previously. Narrow low frequency beams with insignificant side lobes can be obtained with this technique. These beams offer attractive possibilities for compact low frequency sonar if fast scan and high information rates can be achieved. The results of a program to investigate scan methods and to develop a system to achieve high scan rates is reported here. It should be noted that much of the discussion of the theory of coded pulse modulation relies upon work done by Dr. H. O. Berkay and others at The University of Birmingham, England.

This report covers work under Contract N00014-70-A-0166, Task 0008, between 1 December 1972 and 30 September 1973.

II. THE SCANNING OF PARAMETRIC ACOUSTIC BEAMS

The scanning problem for parametric sonar differs from the scanning of linear sonar in that the former transmits a narrow scanned beam and receives echo returns with a wide beam hydrophone. The beamwidth of the hydrophone is as large as the scan sector. In such a system, the azimuth position of an echo return is determined by the position of the transmitted beam at the time of transmission. Thus, the position of the transmitter beam at the time the signal is transmitted must be known at that instant in time when an echo from that transmission is received. The simplest method of determining the transmitter beam position is by transmitting a signal and waiting for all echo returns before allowing another transmission at a different azimuth angle. This method, however, yields a very slow information rate. An increase in information rate can be achieved by labeling the transmitted signal with a signature that corresponds to the azimuth angle of the beam. The receiver then recognizes this signature and determines the angle of the beam at the time the signal was transmitted and the angle of the target from which the signal was reflected.

The signature mentioned above is placed on the transmitted signal with some form of modulation, which requires signal bandwidth that could otherwise be used to achieve higher range resolution. Stated differently, modulation employed to increase the information rate causes a decrease in range resolution for a constant bandwidth receiver. This section presents the results of a comparative study of information rates that are theoretically obtainable from four different scan methods.

A. General Discussion

In order to compare information rates for high resolution sonar, the information rate must be defined. Brown¹ defines information rate for

sonar by considering a sonar as a single noiseless information channel and applying information theory to that channel. A message received on the channel is the acoustic reflectivity distribution of the search area. Each message has associated with it a statistical entropy, which is a measure of its information content. This entropy is given by

$$H = - \sum_{i=1}^M P_i \log_2 P_i \text{ bits/message} ,$$

where

M = the number of possible messages which could be received, and

P_i = the probability of receiving a given message.

If $P_i = 1/M$, then entropy reduces to

$$H = \log_2 M \text{ bits/message} .$$

The entropy as defined above gives the average number of bits in a message, but it does not indicate anything about the time required to collect or receive the message. The time required to receive a message is essential to the definition of information rate. A look is therefore defined as a single interrogation of the sonar scan area, performed in a specified period of time. The following example illustrates the relation between a look and a message. Let a message be received by a sonar in a look. If the sonar looks at the same physical area again and again, the same message will be received with each look. Hence, only one message would be received although many looks were performed.

The message received in one look of the sonar system is one of a set of M_L possible messages, with M_L given by

$$M_L = L \frac{r}{\Delta r} \left(\frac{\pi}{\theta} \right) ,$$

where

r = maximum range (meters),

Δr = range resolution (meters),
 ϕ = angular scan sector (degrees),
 θ = angular resolution (degrees), and
 L = the number of resolution levels with which reflectivity can
be measured (depends on operator, phosphor, etc.).

The set of M messages exists because each message contains $(r/\Delta r) \times (\phi/\theta)$ bits and each bit can have one of L possible values. Furthermore, each message must differ from all others by at least one bit.

The $r/\Delta r$ term in the above equation is the number of range resolution elements in one look and is represented by

$$n_r = \frac{r}{\Delta r} .$$

The ϕ/θ in the same equation is the number of azimuth resolution elements in one look and is represented by

$$n_b = \frac{\phi}{\theta} .$$

Because a look occurs in a specified time, the information rate can be specified if the number of bits in a look can be determined. The number of bits is given by the look capacity, or entropy (H_L), which is defined in a manner similar to message entropy, as shown below.

$$H_L = \frac{r}{\Delta r} \frac{\phi}{\theta} \log_2 L \text{ bits/look}$$

$$H_L = n_r n_b \log_2 L \text{ bits/look}$$

The information rate can now be defined as

$$N_r = \frac{H_L}{T_L} \text{ bits/sec} ,$$

where T_L = the time required for one look (seconds). This assumes that the sonar is looking continuously or that there is negligible dead time.

H_L can be simplified if L is assumed to be 2; therefore $H_L = n_r n_b$. This is a valid simplification, because the object of this study is the comparison of sonar systems and the value of L is heavily dependent upon the operator-display system. The setting of $L=2$ is equivalent to a two-level decision indicating that the point in the look area is either acoustically reflective or nonreflective.

The values of N_r for the four scan systems were calculated to give a basis of comparison for the following discussion. A summary of the calculation results is given in Table I. The undefined terms used in the comparison are

τ - real time transmitted pulselength (seconds),
 W_τ - effective bandwidth (hertz),
 W_t - system bandwidth (hertz),
 W_f - total system bandwidth (hertz),
 c - speed of sound (meters/second), and
 T_m - sound travel time to and from maximum range (seconds).

B. cw Pulse Transmission

The calculations are first presented for the cw pulse system. Here a pulse is transmitted and the return is received one azimuth segment at a time. An azimuth segment covers the area inside the transmitted beam. The information rate for this type of system is

$$N_r = \frac{H_L}{T_L} = W_\tau \text{ bits/sec} .$$

The information rate is limited by the look time T_L which is

$$T_L = \frac{2 \cdot r \cdot n_b}{c} .$$

TABLE I

COMPARISON OF MODULATION METHODS

SCAN TECHNIQUE	EFFECTIVE BANDWIDTH	RANGE RESOLUTION	LOOK TIME (seconds)	INFORMATION RATE (bits/second)
cw Pulse	$W_\tau = \frac{1}{\tau}$	$\Delta r = \frac{c}{2W_\tau}$	$T_L = \frac{2 \cdot r \cdot n_b}{c}$	$N_r = W_\tau$
Pulsed Frequency Shift Transmission	$W_\tau = \frac{1}{\tau} = \frac{n_b}{T_m}$ $W_t = n_b W_\tau$	$\Delta r = \frac{c}{2W_\tau}$	$T_L = \frac{2r}{c}$	$N_r = W_\tau \cdot n_b$ $N_r = W_t$
Pulsed Frequency Shift Transmission with FM Slide (Pulsecomp)	$W'_\tau = m\tau$ $W_t = W_\tau$	$\Delta r = \frac{c}{2W'_\tau}$	$T_L = \frac{2r}{c}$	$N_r = W'_\tau \cdot n_b$ $N_r = W_t$
Coded Pulse	$W_\tau = \frac{1}{\tau}$ $W_t = \frac{N_f}{\tau}$	$\Delta r = \frac{c}{2W_\tau}$	$T_L = \frac{2r}{c}$	$N_r = W_t \cdot \frac{n_b}{N_f}$

C. Pulsed Frequency Shift Transmission

The next consideration is a pulsed frequency shift (PFS) transmission, where a series of single cw pulses with different carrier frequencies is transmitted, one pulse in each sector. This modulation form has a look time of

$$T_p = \frac{2r}{c}$$

and an information rate of

$$N_r = \frac{H}{T_p} = W_t n_b \text{ bits/sec}$$
$$= W_t \text{ bits/sec} .$$

The advantage of this system over the single pulse system is that the information is updated n_b times faster; however, to gain advantage, receiver bandwidth must be increased by a factor of n_b .

D. Pulsed Frequency Shift Transmission with a Linear FM Slide

If the carrier frequency of the PFS transmission described above is changed linearly with time, then the PFS transmission with a linear FM slide results. This type of transmission is described by Bartberger.² If there is no Doppler shift, the range resolution of this type of transmission is given by

$$\Delta r \approx \frac{c}{2m\tau} ,$$

where

τ is the pulselwidth (second), and

m is the time rate of change of frequency (hertz/second).

Improvement in the range resolution of this system for a constant maximum range can be achieved either by increasing the pulsedwidth and the number of analyzer channels or by increasing the slope of the FM sweep and thus the total receiver bandwidth. The pulsedwidth can be increased to

$$\tau_{\max} = \frac{T_{\ell}}{n_b} = \frac{2r}{cn_b} \text{ (seconds)}$$

for a single beam transmission. Increasing the slope (m) of the FM sweep would cause a proportional increase in receiver bandwidth according to

$$W_t = m \cdot \tau_{\max} \cdot n_b .$$

The look capacity for the FM pulse is

$$H_{\ell} = n_b \frac{r}{b\Delta r} = T_{\ell} m \tau_{\max} n_b .$$

The information rate is then

$$N_r = \frac{H_{\ell}}{T_{\ell}} = m \cdot \tau_{\max} \cdot n_b = W_t .$$

The bandwidth limitations for this system are illustrated in this equation. For a constant receiver bandwidth, the range or azimuth resolution can be improved but the information rate remains constant. Thus, if range resolution is improved, azimuth resolution is degraded, and vice versa. This system is, however, superior to both the cw pulse and the PFS systems; it has a shorter look time than the former and can employ a longer pulse than the latter for a given range resolution, resulting in an increase in the average transmitted power and the signal-to-noise ratio.

E. The Coded Pulse Transmission

1. General Discussion

The coded pulse transmission system is the most promising possibility considered. It is therefore the subject of the remainder of this section and all subsequent sections of this report. The development of this technique will be more detailed than for those previously covered. It will start with a discussion of the information rate which was the criterion for its selection, followed by a discussion of the receiver correlator and the methods used for code word selection.

A preview of the general aspects of this technique will be helpful to understanding the detailed discussion. The coded pulse system transmits a sequence of pulses (code words) with various carrier frequencies into the azimuth sectors. Each sector is sequentially scanned once during the look time (T_l). Since a given azimuth sector is always scanned with the same pulse sequence, the wide beam receiver must use replica correlation to recognize and to sort the returning pulse sequences from the various azimuth sectors. Figure 1 illustrates this modulation technique for four azimuth sectors.

2. Information Rate

The coded pulse system has a single pulse bandwidth

$$W_\tau = \frac{1}{\tau} \quad ,$$

but it has a maximum word bandwidth that is given by

$$W_\tau = \frac{N_f}{\tau} \quad ,$$

where N_f is the number of possible carrier frequencies employed by the system. The word bandwidth describes the bandwidth in units of hertz,

f_1, f_2, f_3 and f_4 Represent different carrier frequencies

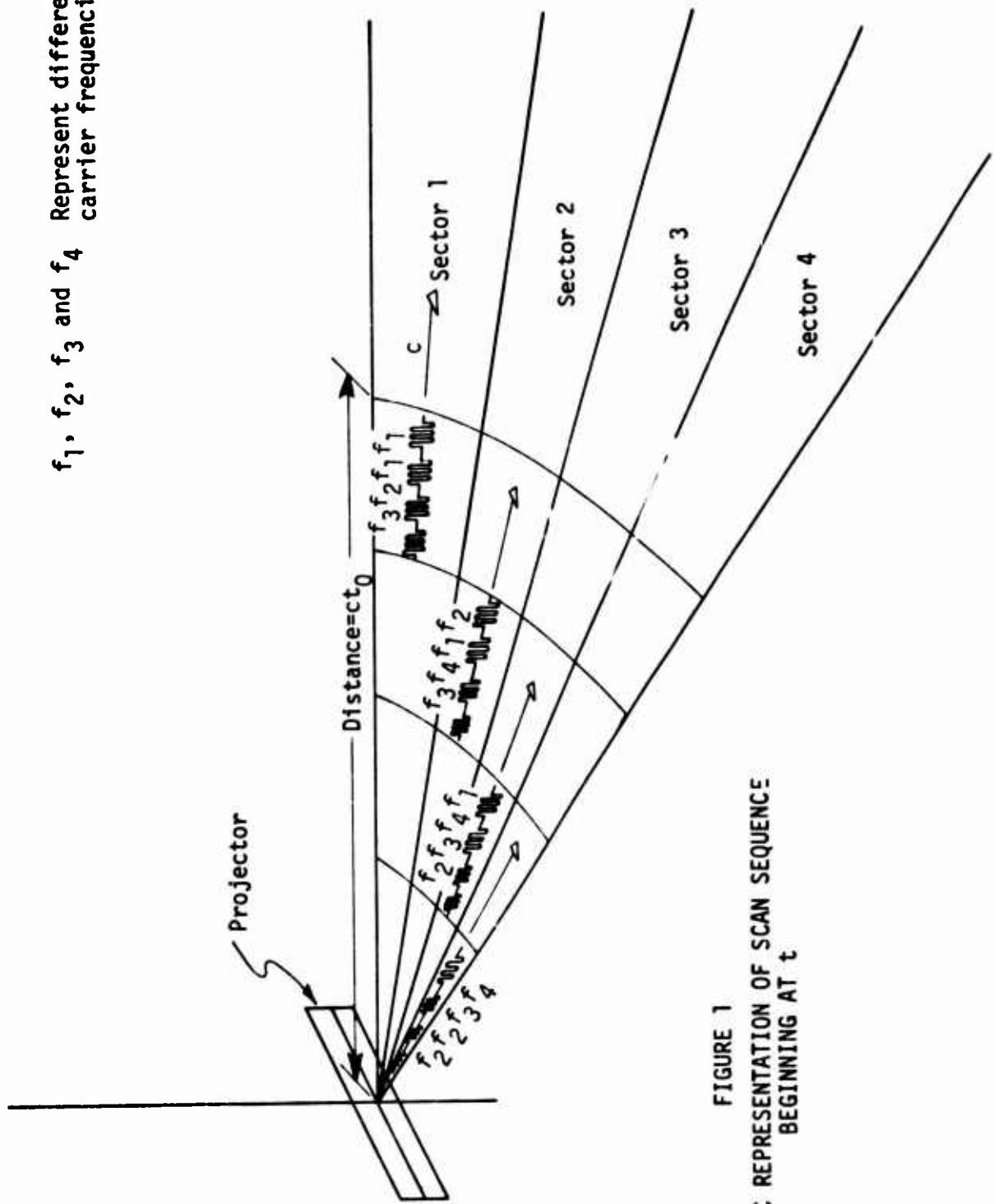


FIGURE 1
GRAPHIC REPRESENTATION OF SCAN SEQUENCE
BEGINNING AT t

which is occupied by the frequency spectrum of the sequence of pulses which constitutes a word. The receiver must have the same bandwidth as the word spectrum.

The look time is

$$T_L = \frac{2r}{c} .$$

The look capacity is

$$H_L = \frac{T_L}{\tau} n_b = T_L W \tau n_b = \frac{T_L W t n_b}{N_f} \text{ bits/look} ,$$

which leads to the maximum information rate of

$$N_r = \frac{W t n_b}{N_f} \text{ bits/sec} .$$

The above equation shows that the information rate can exceed the receiver bandwidth if the factor n_b/N_f can be made greater than one. To determine if this increase is possible, more information is needed about the relationship between n_b and N_f . Because one code word is required for each scan sector, the number of sectors n_b corresponds to the number of unambiguous code words required for sector identification. If the code word is a series of A pulses having one of N_f possible carrier frequencies, then the set of words from which n_b words can be chosen has $N_T = (N_f)^A$ members. If ambiguities were acceptable and if all N_T words in the set were used, then

$$N_r \leq \frac{W t N_f^A}{N_f} = W t N_f^{(A-1)} ,$$

where A = the length of the code word (bits), and

N_f = the number of possible carrier frequencies.

This equation sets the upper theoretical limit of the information rate

if words are allowed to differ by only one member. However, since ambiguities between multiple returns arriving simultaneously must be minimized, the number n_b of words that are actually available is drastically limited to numbers less than N_T . Further description of the receiver system is necessary to show how ambiguity limits the number of code words available from a set.

3. The Receiver System

The coded pulse receiver system was proposed by Berkay.³ It identifies a given code word by means of a correlator containing all n_b words employed by the system. It has n_b outputs, one for each word which could possibly be identified. A block diagram of the receiver system is shown in Fig. 2. The instantaneous output for the (jth) word in the correlator as the (ith) word passes through the correlator is the cross-correlation function given by

$$R_{(i)jk} = \sum_{\ell=1}^{A-|k|} a_{i\ell} a_{j(\ell+|k|)} \quad , \text{ for } k \leq 0$$

$$R_{(i)jk} = \sum_{\ell=1}^{A-|k|} a_{i(\ell+|k|)} a_{j\ell} \quad , \text{ for } k \geq 0$$

where

$a_{i\ell}$ is the ℓ th pulse of the i th code word, and

k is the number of pulses of the i th word which are not in the correlator. ($k < 0$ where a word is entering the correlator, $k = 0$ when the word is completely in the correlator, and $k > 0$ when the word is leaving the correlator.)

Figure 3 illustrates a word six pulses long entering the correlator from left to right. Here $N_f = 4$, $A = 6$, and $k = -5$.

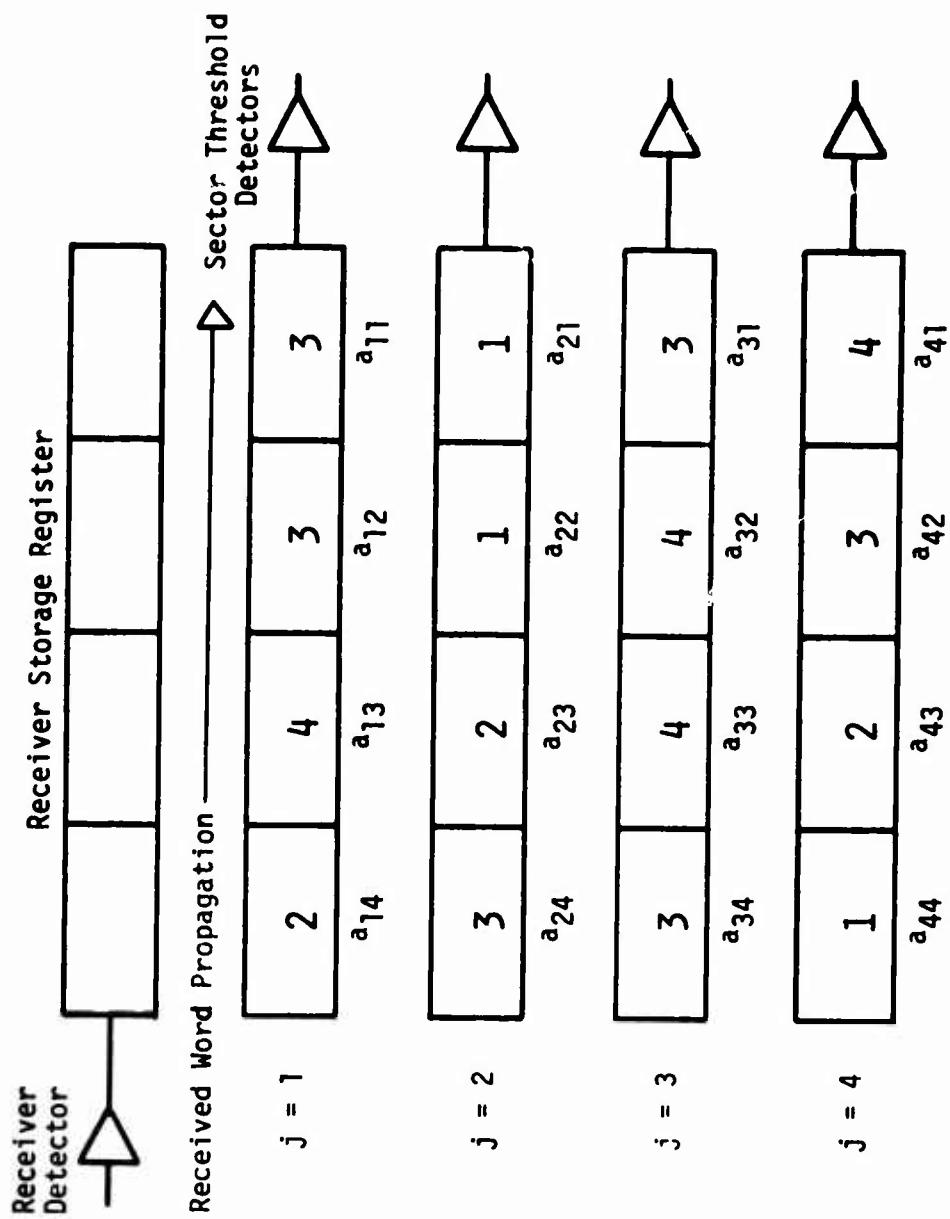


FIGURE 2
REPRESENTATION OF REPLICA CORRELATOR IN A WIDE BEAM RECEIVER

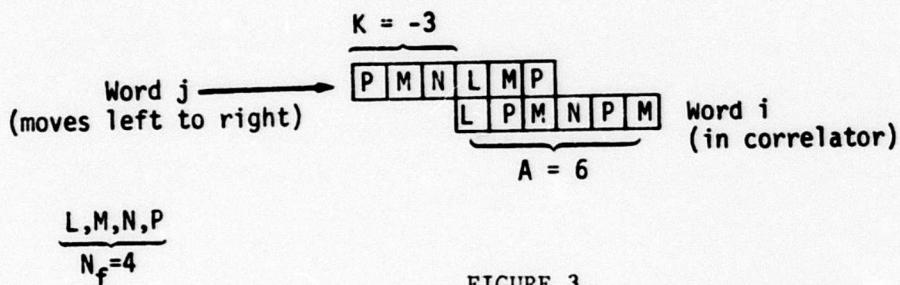


FIGURE 3
ILLUSTRATION OF WORD PASSING THROUGH CORRELATOR

A description of the correlator in operation will clarify the meaning of $R_{(i)jk}$. As the first pulse of a returning signal is received, it is stored in the leftmost block of the receiver storage register. There it is simultaneously compared with the last bit of each sector code. If the received bit equals the sector code's last bit, a one is produced at the output of that sector. This one appears at the input of the sector threshold detector. If the two bits are not equal, a zero is produced. Next, the second pulse of the received signal arrives. It is also stored in the leftmost block and the first pulse is shifted one block to the right. The first pulse is now compared to the third bit of each stored word and the second pulse is compared to the fourth. If the first pulse equals the third and the second equals the fourth, a two is produced at the threshold detector for that sector. This process continues until the received word is completely in the receiver storage register. If the received word and the stored word are the same, bit for bit, then a four is produced at the threshold detector for that sector. If the threshold detector is set to indicate a target only when an input of four occurs, then the received signal must, first, be completely in the correlator and, second, must perfectly match the sector code. Under these ideal conditions, the code words must differ by only one bit to give unambiguous target indications. In practice, the threshold must be set to some number $T < A$ to increase the probability of detection. When the threshold is set at T , then the allowable number of like bits or the crosscorrelation between two codes must be reduced to $R_m \leq T$ in order to prevent ambiguities in the correlator. As the difference between R_m and T

becomes larger and larger, the system has more noise immunity. However, as R_m is made smaller, the number of words available from a given set is reduced. Therefore, a system must be developed to find which words in a given set meet the requirements $R_{(i)jk} < R_m$ for all k and $R_{(i)ik} < R_m$ when $k \neq 0$.

4. Code Word Selection

A process to find a group of words for a given set of parameters, N_f , A , and R_m was developed by Berkay.³ A set of sequences $R_m + 1$ bits long is compiled. There exist

$$N_f^{R_m + 1}$$

of these sequences. These sequences are then used only once to form words A bits long. When a sequence is used in a word, it is discarded. Each word contains $(A - R_m)$ sequences that are $R_m + 1$ long, and each sequence differs by at least one bit. The maximum number of words available is then

$$B_{\max} < \frac{N_f^{R_m + 1}}{A - R_m} .$$

Consideration of sequences of length $(R_m + 2)$, $(R_m + 3)$, ..., and of the probability that they have $R_m + 1$ coincidences with other sequences of the same length leads to a minimum number of available code words. Thus,

$$\frac{N_f^{R_m + 1}}{C_A^{R_m + 1}} < B_{\max} < \frac{N_f^{R_m + 1}}{A - R_m} ,$$

where $C_A^{R_m + 1}$ is the number of ways A values can be arranged, with no concern for the order of arrangement, in sets containing $R_m + 1$ bits. Since

$B_{\max} = n_b$, the information rate N_r can be

$$\frac{\frac{W_t N_f}{R_m + 1}}{\frac{C_A}{R_m}} \leq N_r \leq W_t \frac{N_f}{A - R_m} .$$

To achieve information rates higher than those obtained with the systems discussed above, the condition

$$\frac{\frac{-R_m}{N_f}}{\frac{C_A}{R_m + 1}} > 1$$

or

$$\frac{\frac{-R_m}{N_f}}{\frac{A!}{(R_m + 1)!(A - R_m - 1)!}} > 1$$

must be met.

The number (B_{\max}) of code words available is given for different values of N_f , A , and R_m in Table II. These numbers represent the minimum number of code words theoretically available if only one target return is present in the correlator at a given time. The presence of multiple target returns in the correlator causes ambiguous or nonexistent targets to appear. Since the correlator must process all target returns simultaneously, it can interpret sequences consisting of bits from two different words as a target return in a different sector. This problem occurs when any sequence of consecutive bits from any one of the words in the correlator has a crosscorrelation function greater than R_m with another sector word in the correlator. The presence of these ambiguities limits the number of available words to much fewer than the number given in Table II.

The specific words with favorable crosscorrelation and autocorrelation properties can be found by choosing a word and comparing it

TABLE II
MINIMUM NUMBER OF WORDS AVAILABLE FOR
VARIOUS VALUES OF N_f , A , AND R_m

N_f	A	R_m	B_{min}^*	N_f	A	R_m	B_{min}^*	N_f	A	R_m	B_{min}^*
4	4	2	16		7	2	13		6	7	34,992
	3		256		3		17		7		1,679,616
5	2		6		4		148		2		
	3		51		5		2,232		3		10
6	4		1,024		6		78,125		4		61
	2		3		8		2		5		555
	3		17		3		8		6		7,776
	4				4		55		7		186,624
7	5		4,096		5		558				10,077,696
	2		1		6		9,765		2		85
	3		7		7		390,625		3		2,401
	4		98	5	9	2	1		2		34
	5		585		3		4		3		480
8	6		15,384		4		24		4		16,807
	2		1		5		186		2		17
	3		3		6		2,170		3		160
	4		18		7		43,402		4		2,801
	5		146		8		1,953,125		5		117,649
	6		2,048	6	4	2	54		2		9
	7		65,536		3		1,296		3		68
9	2	0			5	2	21		4		800
	3	2			3		259		5		16,807
	4	8			4		7,776		6		823,543
	5	48			6	2	10		7		6
	6	455			3		86		3		34
	7	7,281			4		1,296		4		300
5	4	2	262,144		5		46,656		5		4,201
	3	31			7	2	6		6		102,942
	5	625			3		37		7		5,764,801
	2	12			4		370		2		4
	3	125			5		0,665		3		19
	4	3,125			6		279,936		4		133
6	2	6			8	2	3		5		1,400
	3	41			3		18		6		22,876
	4	520			4		138		7		640,533
	5	15,625			5		1,666		8		40,353,607

$$B_{min}^* = \frac{N_f}{C^A_{R_m+1}} \quad , \text{ where } C^A_{R_m+1} = \frac{A!}{[R_m+1]![A-(R_m+1)]!}$$

to the other words in the selected set. The words should be selected by forming all possible sequences $R_m + 1$ long as outlined above. These sequences are combined to form words, with each sequence being used only once. Autocorrelation and crosscorrelation with all other selected words are then performed. If the correlation tests yield $R_{ijk} < R_m$ for all (i, j, k) , then the word is added to the set of acceptable words. If $R_{ijk} > R_m$ for any (i, j, k) , the word is rejected and the sequences are returned to the set of available sequences. The correlation tests should be performed using a digital computer.

F. Application of Coded Pulse Technique

The theory and discussion about word selection assume that there is a high signal-to-noise ratio in the incoming signal and that the words are strictly evaluations of numbers. They do not give any indication of receiver performance in the presence of noise, reverberation, or multiple targets. It is therefore necessary to evaluate the words selected in a noisy, multitarget situation. The coded pulse scanning system to be described in Section III has been designed to meet this need. The scanning system will transmit the coded pulse sequences which will be reflected from targets and recorded on magnetic tape. The transmitter will also supply the difference frequency and a clock signal to the receiver tape. The receiver, correlation, and timing signals on the tape will be digitized and analyzed by a CDC 3200 digital computer which will perform the replica correlation function described above.

G. Summary

Four modulation methods have been investigated to evaluate their applicability to parametric scanning systems. The most promising of the four is the coded pulse scanning system. It offers an information rate which exceeds the receiver bandwidth if sufficient numbers of code words can be found to give low ambiguities in a multitarget, noisy environment. A coded pulse scanning system has been developed to facilitate testing of code words designed for this system.

III. CODED PULSE SCANNING SYSTEM: DESIGN

A. General Description

The scanned parametric transmitter was designed as a tool for investigation of the pulse coded modulation schemes discussed in the previous chapter. It was designed to transmit a frequency coded sequence of cw pulses (forming a code word) into a preselected azimuth sector. The scan sector is the horizontal angle occupied by the transmitted beam (see Fig. 1). The code word can be any sequence of one to four pulses, with the carrier frequency of each pulse being selected from a set of four frequencies. Four azimuth sectors can be scanned in any sequential order by transmitting a different code word into each sector. Beam-forming is accomplished by using a phased parametric array.

B. Component Subgroups

The total system has been divided into nine subgroups to facilitate the operational description. These subdivisions, indicated in Table III, apply to the function of the subsystem rather than to the physical layout. The following description offers a brief overview of the subsystems as they function in the sequence of signal flow through the system (see Fig. 4). Two signals are present: the modulation signal and the carrier signal. The description begins with generation of the modulation signal. The scan generator and the code selector panel, respectively, generate and control the modulation signal; this signal modulates the carrier signal which was generated in the oscillator. The modulation of the carrier occurs in the sector selector subsystem. The modulated carrier signal then flows from the sector selector to one of the delay lines which determine beam steering angle. The delay lines have 42 outputs and produce 42 replicas of the modulated carrier input, each replica having a different time delay. Each of the delayed replicas is subsequently

amplified by its own driver and power amplifier. Each power amplifier output is transformed by the matching networks to drive one of 42 projector staves. Thus, the projector staves are each driven by one of the delayed replicas to produce the steered acoustic beam.

TABLE III
FUNCTIONAL SUBSYSTEMS OF THE
SCANNED PARAMETRIC TRANSMITTER

- | | |
|------------------------|----------------------|
| 1. Scan Generator | 6. Drivers |
| 2. Code Selector Panel | 7. Power Amplifiers |
| 3. Oscillator | 8. Matching Networks |
| 4. Sector Selector | 9. Projector |
| 5. Delay Lines | |

This concludes the brief perspective of how the nine subsystems work within the whole design. What follows are individual descriptions of each of these subsystems.

1. Scan Generator

The scan generator provides both a clock frequency that determines the transmitted pulselwidth and a time sequenced output that controls the time of transmission of a given pulse to a given sector. A functional schematic of the generator is given in Fig. 5.

The clock is an astable multivibrator operating through an interrupt gate at a frequency of 500 Hz. It drives a monostable multivibrator, which in turn provides a 30 nsec pulse to the pulse counter. The pulse counter has a binary coded decimal (BCD) output which is decoded to a one-of-n output by the pulse decoder. The sector counter is triggered by reset pulses from the pulse counter, and its BCD output is decoded by the sector decoder. The sector reset triggers the blanking monostable, which in turn inhibits the clock and blanks all of the frequency select gates. Thus, no output is obtained from the oscillator

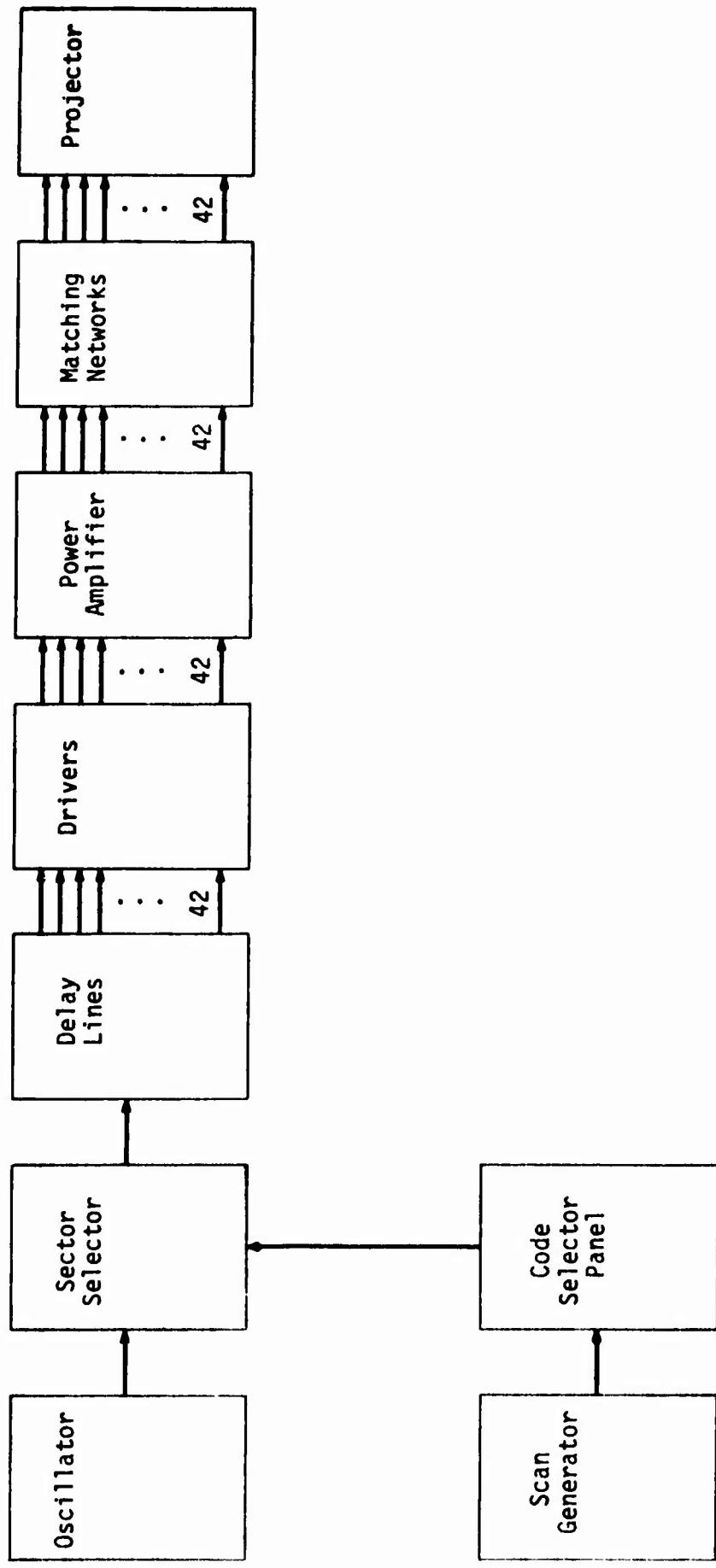


FIGURE 4
BLOCK DIAGRAM OF CODED PULSE TRANSMITTER

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RLW-0166-8

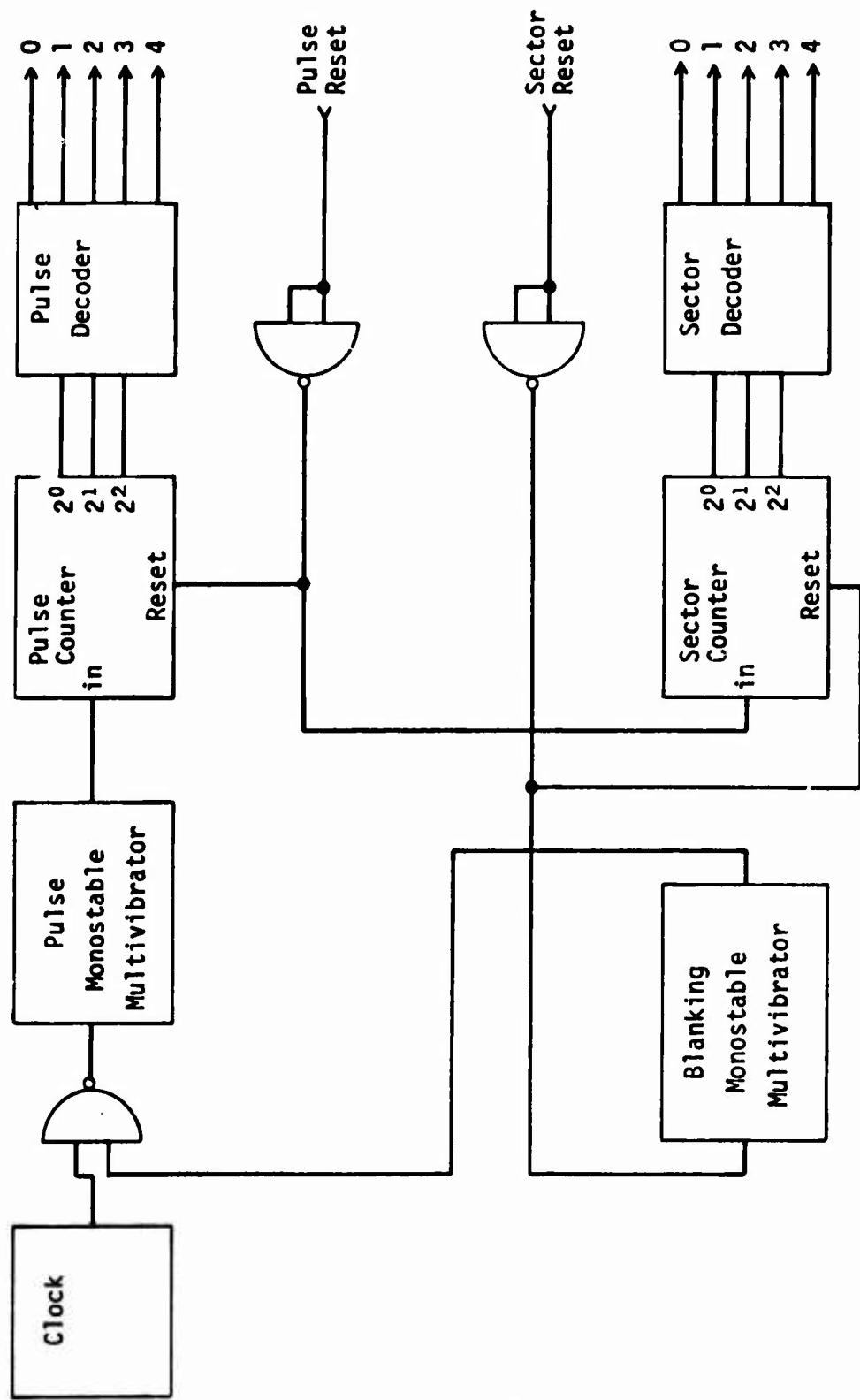


FIGURE 5
SCAN GENERATOR, CODED PULSE SCANNING SYSTEM

during the blanking interval, which is 137 msec long. The scan generator thus provides a pulse-sector code sequence to the code selector panel, where frequency assignments are made for each pulse-sector combination.

2. Code Selector Panel

The code selector panel consists of a patch panel and the necessary logic for assigning frequencies to each pulse-sector code generated by the scan generator. The panel and logic combine to give a 3-variable "AND" function (f_q) at the input of the oscillator transmission gates. This AND function could be represented by

$$n \times m \times \overline{\text{BLANK}} = f_q ,$$

where

n is the pulse number,

m is the sector number,

q is the frequency to be transmitted, and

BLANK is the blanking pulse.

A simplified schematic diagram of the panel is presented in Fig. 6. The gating signals from the code selector panel operate the frequency selection gates in the oscillator.

3. Oscillator

The oscillator is gated by the code selector panel to provide a linear sum of two sinusoidal waveforms. One of these signals is 84 kHz and the other is 70, 72, 74, or 76 kHz, depending upon the state of the frequency code from the code selector panel. The oscillator provides an output only when the blanking pulse from the scan generator is in its zero state.

The oscillator consists of a 1.68 MHz crystal controlled oscillator which is divided digitally to obtain the desired frequencies.

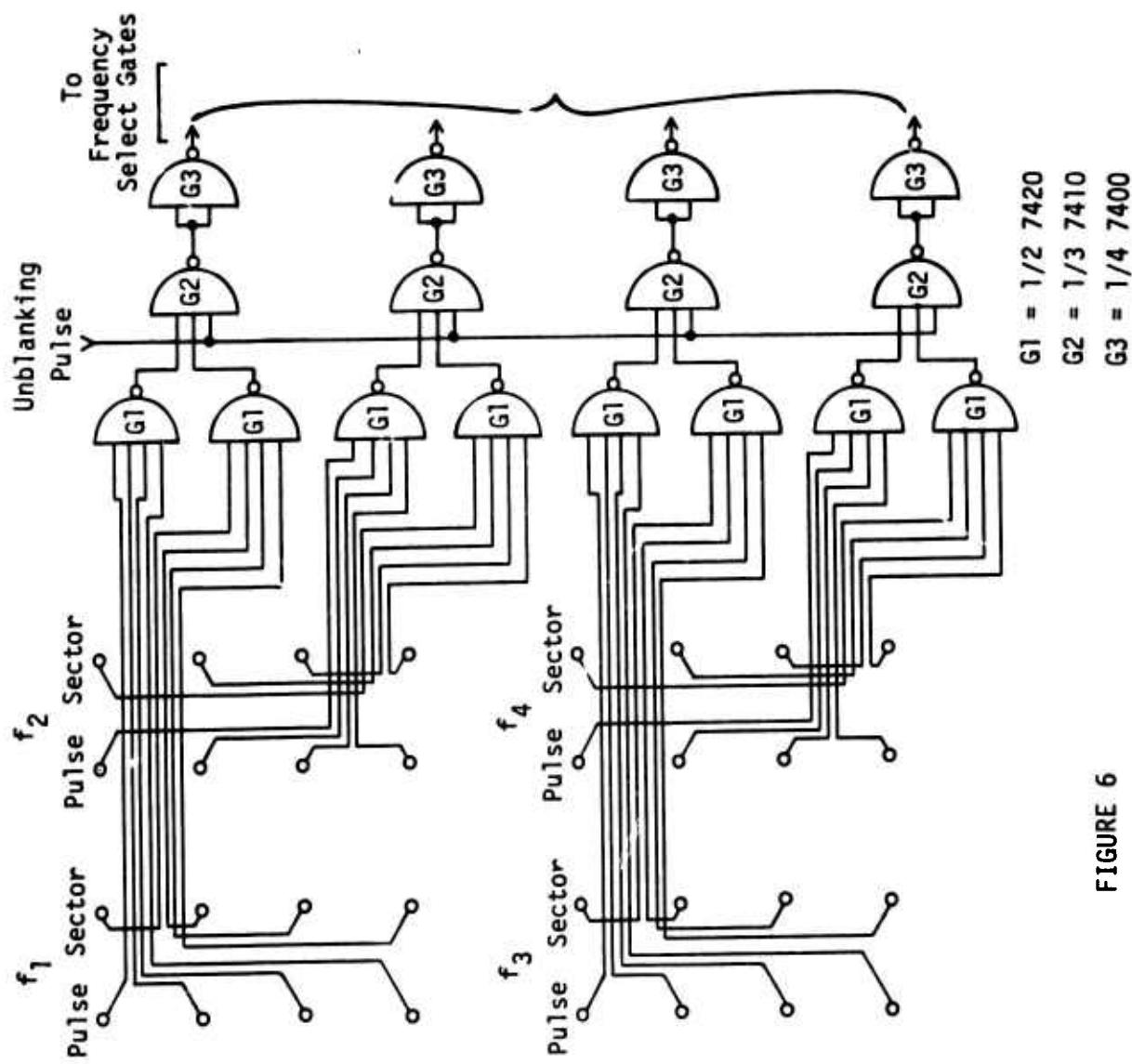
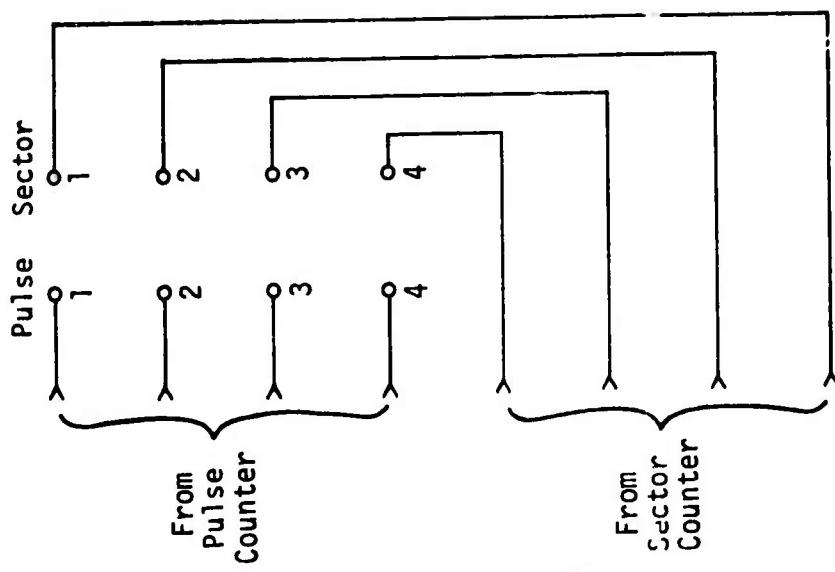


FIGURE 6
CODE SELECTOR PANEL



A functional diagram is shown in Fig. 7. The frequencies obtained by frequency division are 84, 14, 12, 10, and 8 kHz. The four lower frequencies are filtered, gated, and mixed with the 84 kHz signal in a balanced modulator. The output of the balanced modulator is filtered so that the difference frequency is obtained. This difference frequency (76, 74, 72, or 70 kHz) is then linearly summed with the filtered 84 kHz signal to give the linear combination of sine waves. The 14, 12, 10, and 8 kHz signals are gated by the blanking pulse (BLANK) in the code selector panel logic. The 84 kHz signal is gated by BLANK in a gate at the input of the linear summer. The amplitudes of the two primary frequencies are separately controllable by trimmer potentiometers in the oscillator.

4. Sector Selector

Sector selector circuits apply the output of the oscillator to one of four delay lines according to the sector code. The sector selector consists of four gates with common inputs to which the oscillator signal is applied. The output from each of the four gates then drives a separate delay line through a line driver. (See Fig. 8.)

5. Delay Lines

There are 15 delay lines in the delay line subsystem. These lines vary in total time delay from 12.3 μ sec to 184.5 μ sec, which gives a range of scan angles from 1° to 15° in 1° increments. Each line can be driven by a line driver from the sector selector from either end for steering on either side of the projector axis. Each line has 42 output taps, each connected to the input of the power amplifier driver. The wiring of the delay line assembly is illustrated in Fig. 9. The end of each line has a 200 Ω resistive load. The like outputs of all 15 lines are connected through 20 k Ω resistors to a summing junction at the input of the power amplifier driver. The summing junction relieves the necessity for switching the delay line outputs. Average unloaded attenuation in the delay lines is about 28 dB.

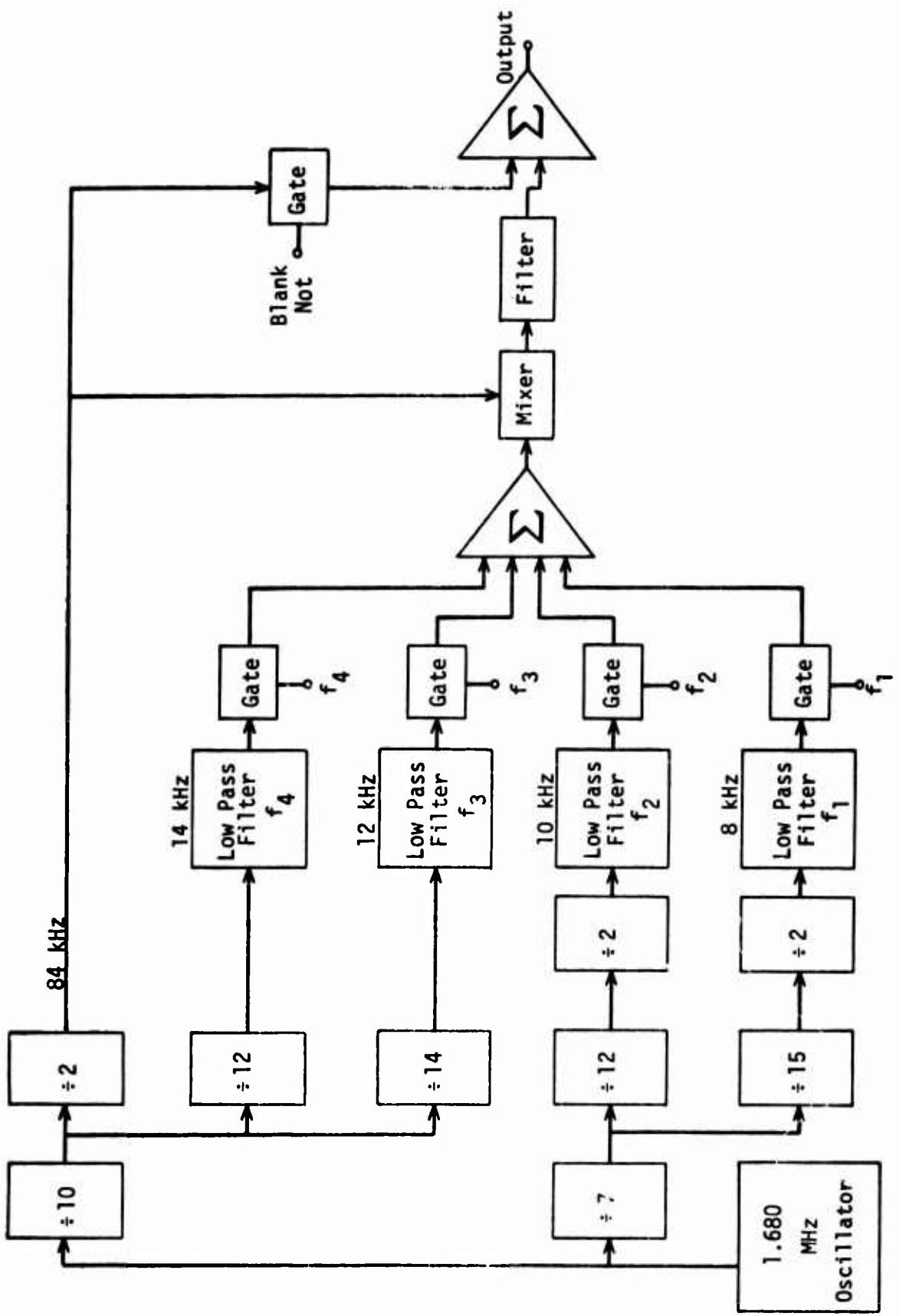


FIGURE 7
OSCILLATOR (CODED PULSE SCANNING SYSTEM)

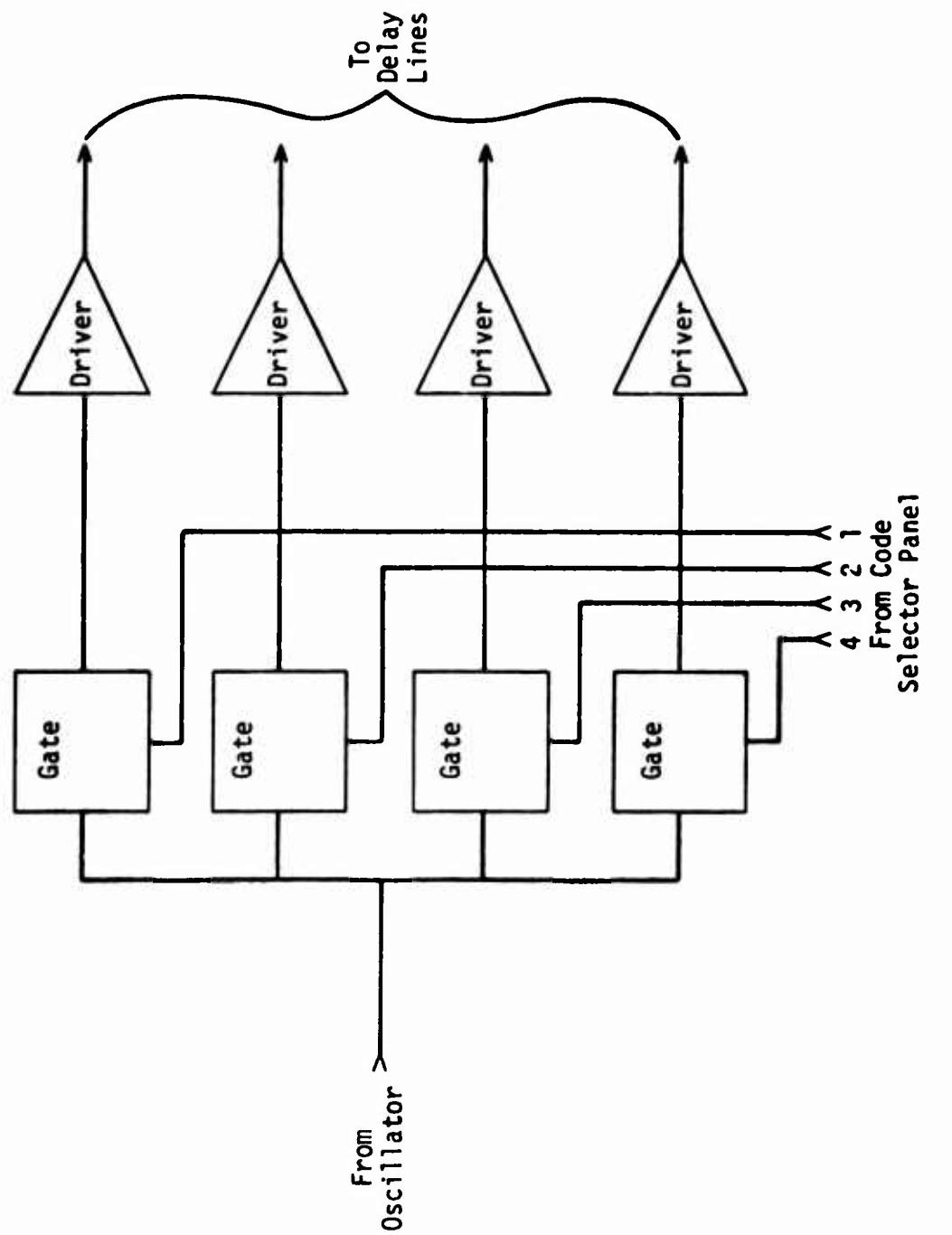


FIGURE 8
SECTOR SELECTOR

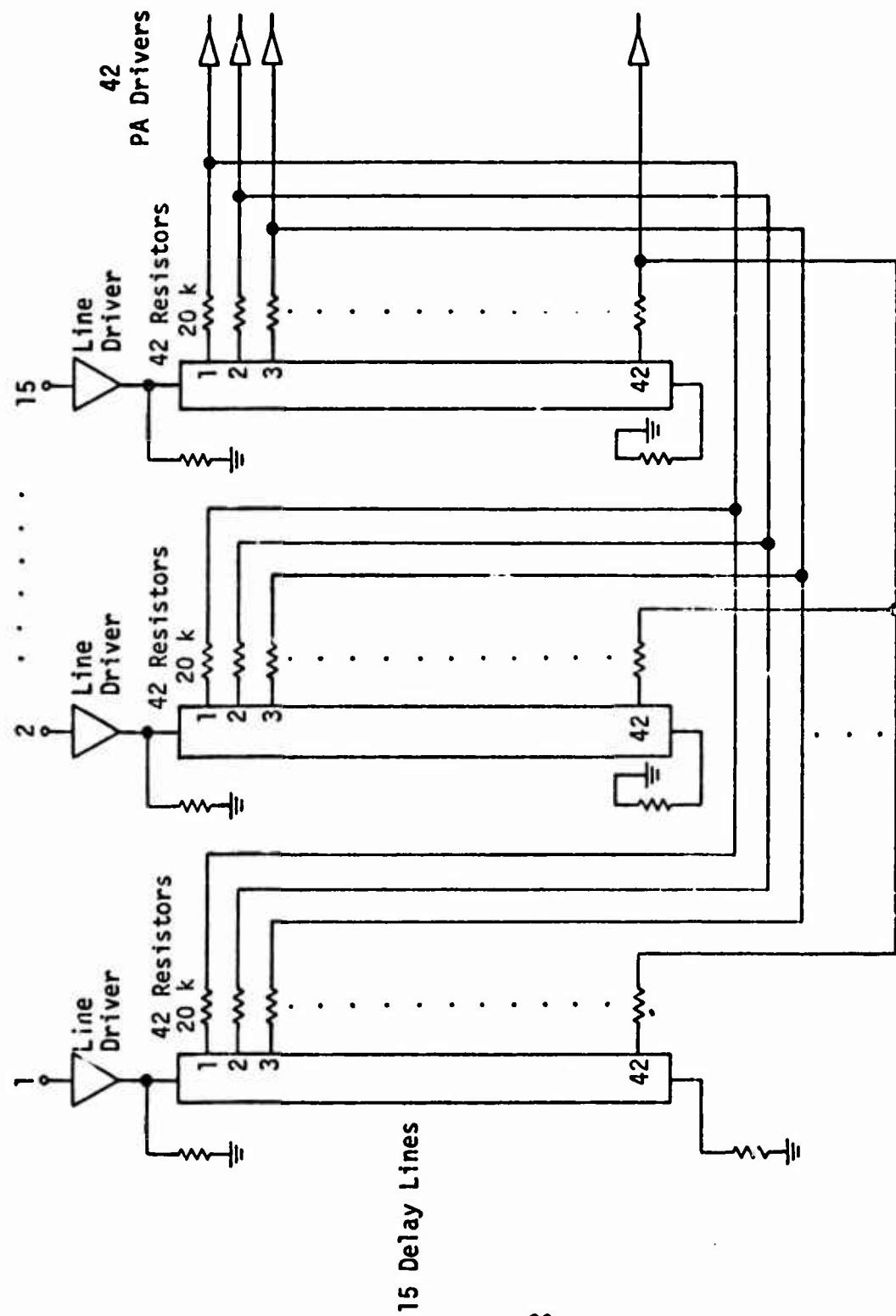


FIGURE 9
DELAY LINE PACKAGE

6. Power Amplifier Driver

The purpose of the power amplifier driver (Fig. 10) is to provide controllable gain and phase compensation for each channel of the transmitter. The driver consists of three transistor stages, including a low level tuned amplifier, a phase shift amplifier, and a final voltage amplifier. The first stage is a common emitter circuit with a single tuned collector having a 15 kHz bandwidth. The second stage is a phase shift network which provides adjustable phase shift from 0° to +95°. The final stage is a common emitter amplifier designed to give additional voltage gain. Its output drives the input voltage amplification stage of the power amplifier.

7. Power Amplifier

The power amplifier (schematic of Fig. 11) is a set of 42 independent modular power amplifiers mounted in a single chassis. Each amplifier is a class AB₁ amplifier capable of supplying a 10 W cw pulse with a 25% duty cycle to an 8 Ω load. This amplifier configuration was chosen for its simplicity, favorable linearity, and low power consumption when no signal is present. The -3 dB frequency response of the amplifier is 25 kHz to 196 kHz when it is driving a 3.4 Ω resistive load. The voltage gain is 27.4 dB into a 3.4 Ω resistive load. The output impedance is 0.5 Ω.

The output stage of this modular amplifier is a class AB₁ push-pull amplifier consisting of MJE 1090 and MJE 1100 power transistors. The MJE 1090 and MJE 1100 are complementary silicon transistors rated at 70 W. The f_t for these transistors is 1.0 MHz. The power transistors are driven by a single voltage amplifier-driver stage employing a 2N4403. An MPS U61 is used in the load of this driver to correct for crossover distortion and to prevent thermal runaway. Figures A-15 and A-16 in the appendix are photographs of the modular power amplifier. The amplifier is constructed on a two-sided glass board; one side contains the circuits and the other a ground plane. All circuit

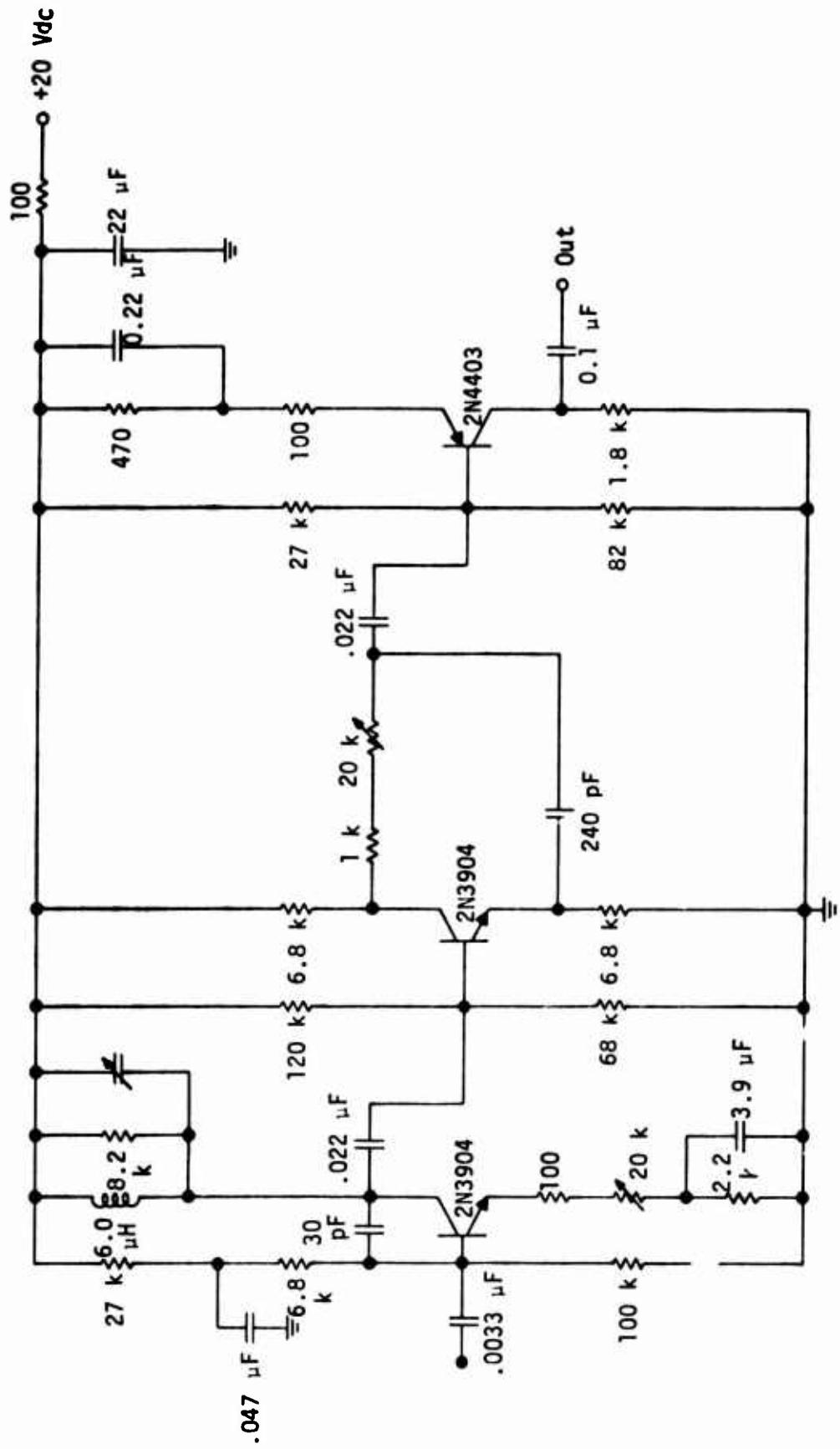


FIGURE 16
POWER AMPLIFIER DRIVER

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RLW-0166-8

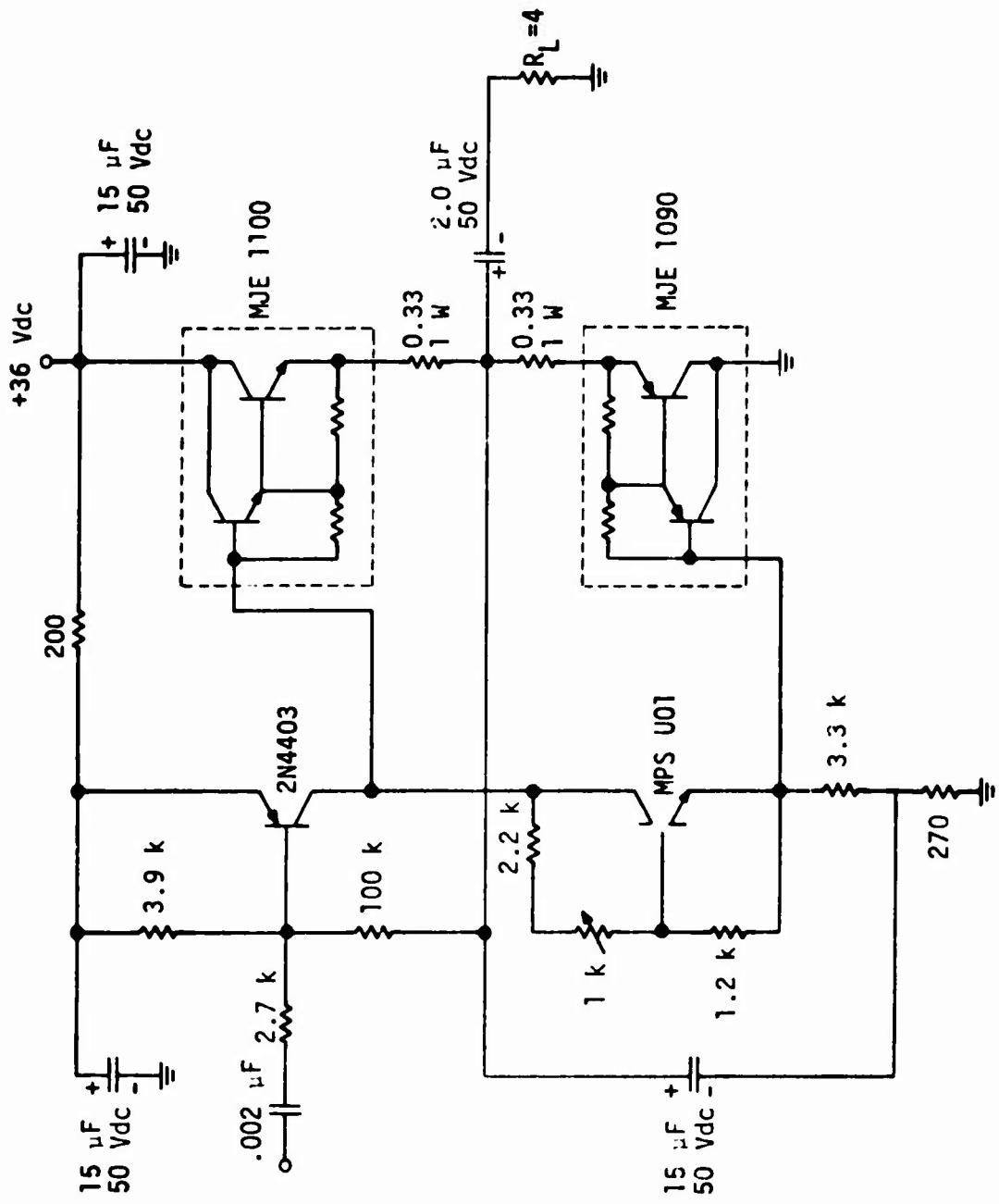


FIGURE 11
POWER AMPLIFIER (CODED PULSE SCANNING SYSTEM)

AS-73-1891
RLW-0166-8

components are mounted on the ground plane side. A metal plate mounted under the power transistors serves as the heat sink which furnishes adequate heat dissipation for full power with a 25% duty cycle. It is not, however, adequate for cw operation, which can cause thermal damage to the power amplifiers.

The power amplifier modules are assembled in a single chassis which supplies heavily filtered dc power. This filtering is provided by 15 parallel connected 9000 μ F capacitors. Further decoupling capacitors are provided on each power amplifier module.

Inputs and outputs to the power amplifiers are provided on the rear of the chassis. Isolation is provided between the connectors and the power amplifiers with coaxial cable. The input cables have common grounded shields at the input connector, while the outputs have floating shields which are grounded as closely as possible to the amplifier. The power amplifier output cable shields are isolated in this manner until they reach the projector staves where they are connected to the common ground projector case.

8. Matching Networks

The matching networks are tuned air core autotransformers which transform the complex projector impedance to 8 Ω resistive at 76 kHz. At other frequencies, the projector impedance reflected to the input of the matching network is complex. The source level does not, however, change more than 3 dB within the band of operation between 69 and 85 kHz.

A schematic diagram of the matching network is shown in Fig. 12(a). The secondary reactance jX_s resonates the projector reactance $-jX_s$ at 76 kHz. The reflected impedance is resistive. The input capacitor is series resonant with the primary reactance causing the entire impedance at the input to be resistive. The input resistance is 8 Ω at 76 kHz.

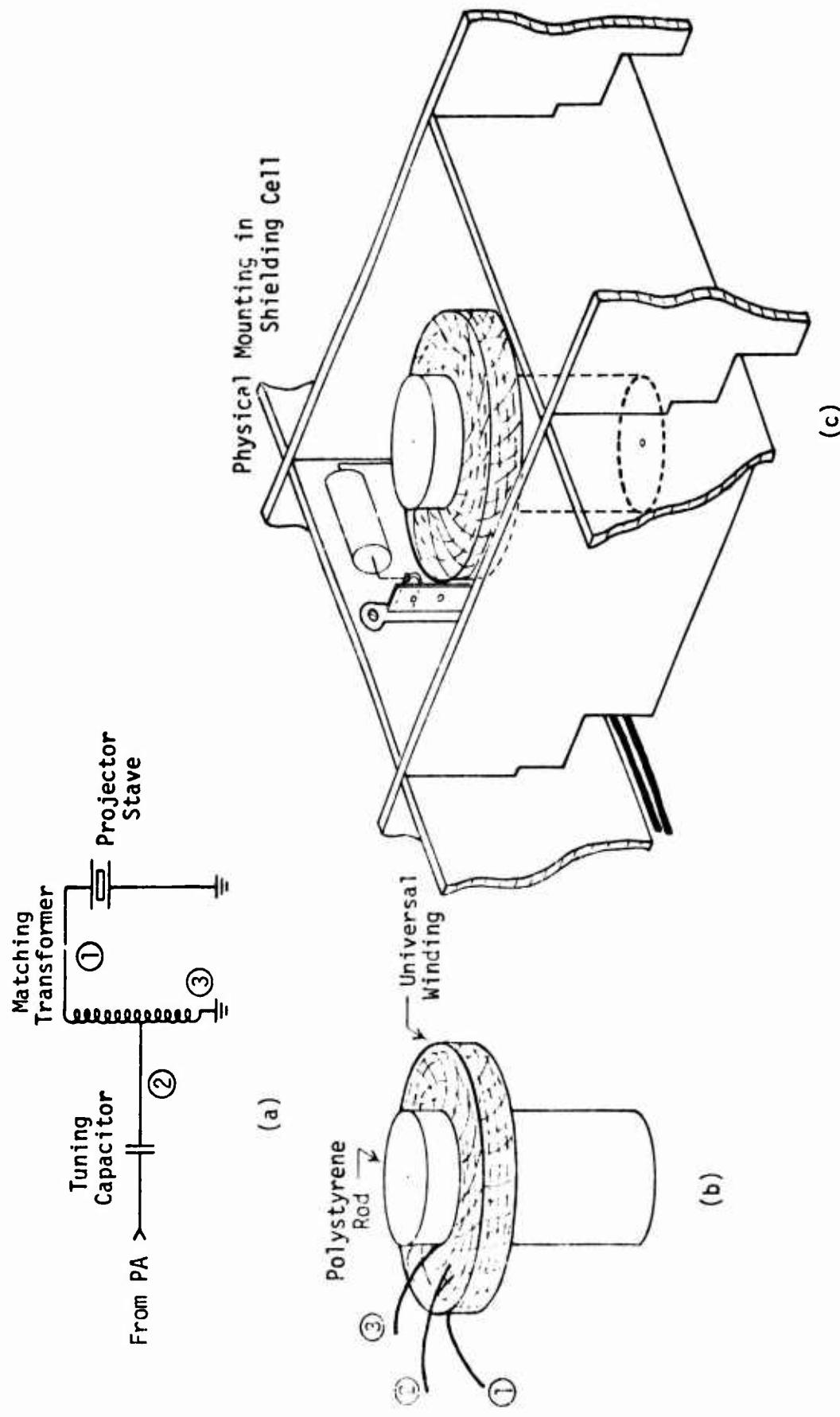


FIGURE 12
IMPEDANCE MATCHING NETWORK (CODED PULSE SCANNING SYSTEM)

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RLW-0166-8

The physical construction and placement of the matching network is shown in Figs. 12(b) and 12(c). The matching transformer is an air wound universal winding on a polystyrene rod. The universal coil is wound with 10-36 litz wire to give maximum Q and maximum efficiency. The coil is an autotransformer in which primary and secondary windings are both part of the same pi wound section to ensure maximum coupling. The measured matching network efficiency (power in/power out) at 76 kHz with the projector connected is 79%.

The autotransformers and input capacitors are mounted in a chassis box which is subdivided with aluminum partitions into 15 equal cubicles. Three chassis provide 45 matching networks and 3 spares. Except for the cable ports, these cubicles totally enclose the matching networks, and thus provide electrostatic shielding to prevent mutual coupling between channels. The network inputs and outputs are connected to the system through connectors on the rear of the chassis.

9. The Projector

The projector is a 42-stave multielement array 42 in. long and 4.5 in. high. Each of the 42 staves has dimensions of 4.5 x 0.940 x 0.625 in. The staves are an assembly of eight ceramic elements 0.94 x 0.507 x 0.625 in. which are stacked on their 0.940 x 0.625 in. faces with 0.069 in. of chloroprene sandwiched between adjacent elements. The elements in each stave are wired in parallel and each stave is driven separately by one of the power amplifiers.

The measured 3 dB beamwidth of the projector, driven at 70 kHz with no time delay between the staves, is 1.7°; the first side lobes are 16 dB down at 3.5° (see Fig. 13). The directivity index of the projector is +34 dB. It was calculated from the above beam pattern with two additional assumptions. The first assumption was that the vertical 3 dB beamwidth was 15°. The second assumption was that all radiated power was within the solid angle formed by the horizontal and vertical beams.

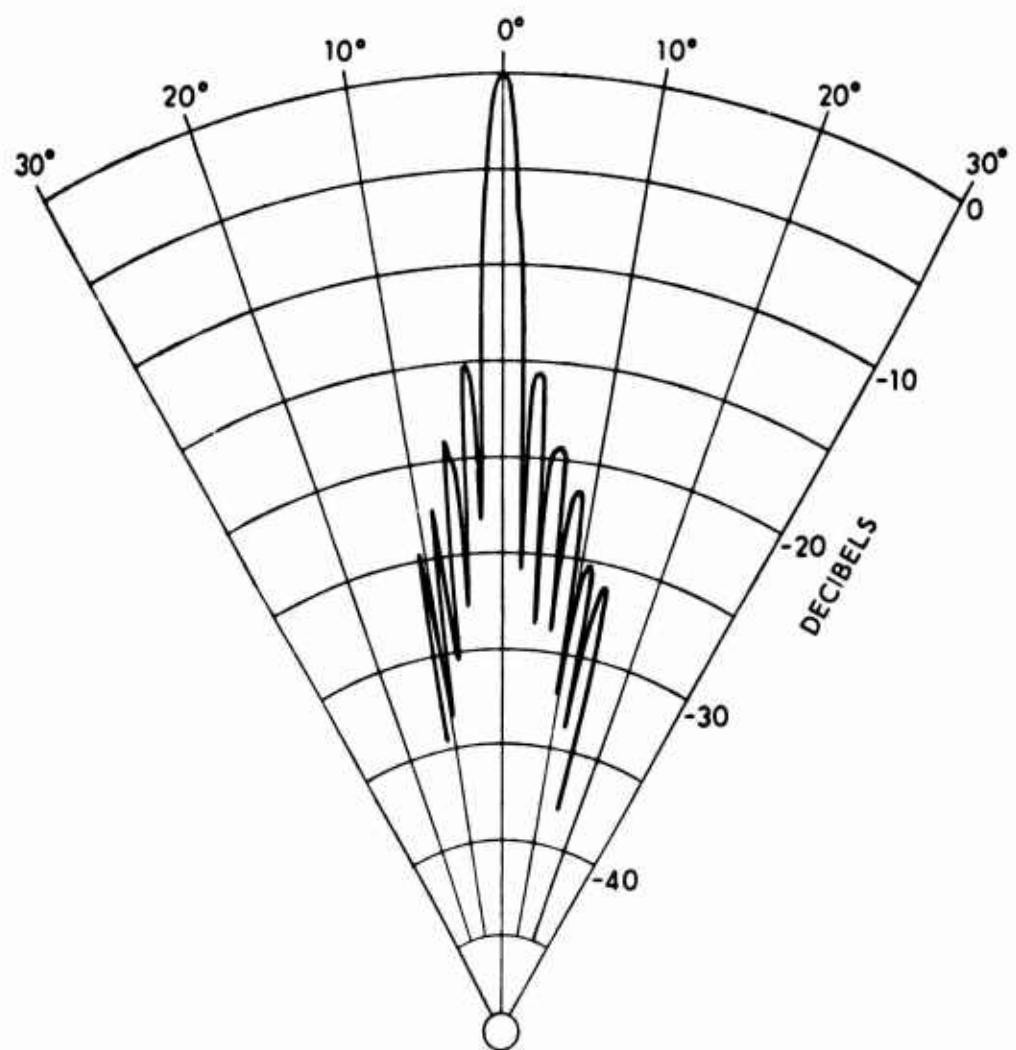


FIGURE 13
POLAR PLOT OF 70.0 kHz BEAM PATTERN
ALL STAVES DRIVEN FROM THE SAME AMPLIFIER

C. Power Supplies

The power supplies for the system include three modular-regulated, current-limiting supplies mounted in a single chassis and one variable-regulated, current-limiting supply in another chassis. The modular supplies provide power to the scan generator and the drivers, while the variable supply drives the power amplifier. The voltages of operation for the modular supplies are +5, -5, and +20 V; the variable supply is operated at +36 V. The variable supply is set to current limit at a level just above the average operating current of the power amplifiers.

IV. CODED PULSE SCANNING SYSTEM: TESTS

Tests were conducted at ARL's Lake Travis Test Station (LTTS) to demonstrate the electronic scanning of a parametric beam and to measure its directivity pattern and source level at various steering angles. Standard pulse techniques of measurement were used. The projector of the coded pulse transmitter was mounted on a rotating column in the water; this column allowed rotation on the azimuth and elevation axes. A calibrated spherical hydrophone was placed in the farfield of the projector to measure the transmitted signal as the projector was rotated in azimuth. The range from the projector to the hydrophone was 67 m. (See Fig. 14.) The voltage output of the hydrophone was filtered, amplified, gated, peak detected, and recorded on the y-axis of a recorder. The scale factor was 5 dB/in. Figure 15 shows the receive system. The x-axis position of the recorder pen was a function of the azimuth position of the rotating projector column. The x-axis scale factor was 3° /in.

The parametric beams were produced by the simultaneous transmission of two primary beams. The carrier frequencies of these primary beams were 70.00 and 83.95 kHz. Before measuring the parametric directivity pattern, however, separate directivity patterns were measured by transmitting only one primary frequency at a time. The parametric directivity pattern was then measured by simultaneously turning on both primary beams without changing input power levels. The calculated radiated acoustic power was 52.5 W.

The directivity patterns for deflected beams of $\pm 1^\circ$, $\pm 7^\circ$, and $\pm 14^\circ$ are shown in Figs. 16 through 18. Figures 16 and 17 show the respective directivity patterns of 70.00 and 83.95 kHz for each deflection angle. A comparison of primary beamwidth to difference frequency beamwidth would be meaningful at this point. The patterns of Figs. 16 and 17 do not,

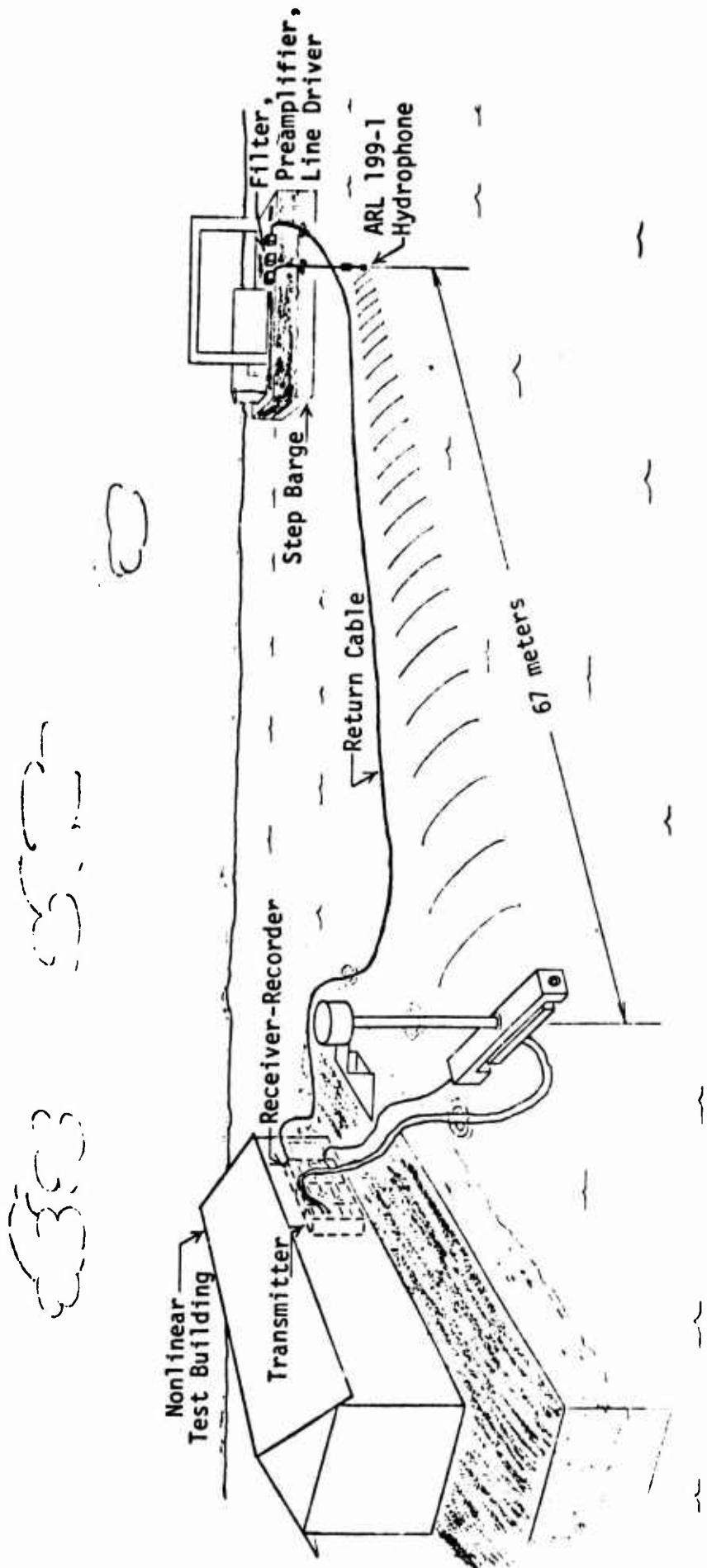
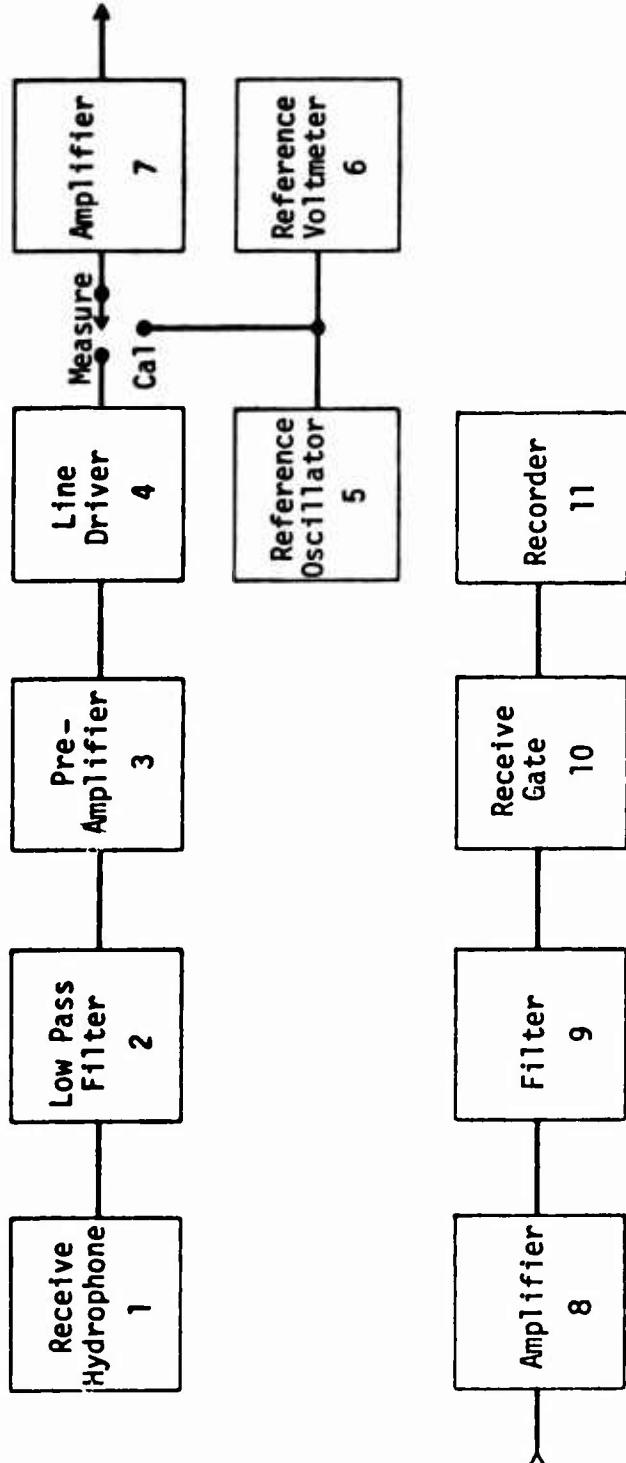


FIGURE 14
CODED PULSE TRANSMITTER EXPERIMENT



List of Equipment

- 1 ARL-199-1
- 2 ARL (No Number)
- 3 ARL (No Number)
- 4 ARL (No Number)
- 5 Hewlett-Packard 204C
- 6 Hewlett-Packard
- 7 ARL (Low Noise Preamplifier)
- 8 Scientific-Atlanta SA-1116
- 9 Krohn-Hite 3100 R (10 kHz to 20 kHz)
- 10 Scientific-Atlanta S-1112
- 11 Scientific-Atlanta

NOTE: Blocks 2 and 3 were omitted during measurements of primary beam patterns.

FIGURE 15
RECEIVER CONFIGURATION DURING LTTS TESTS

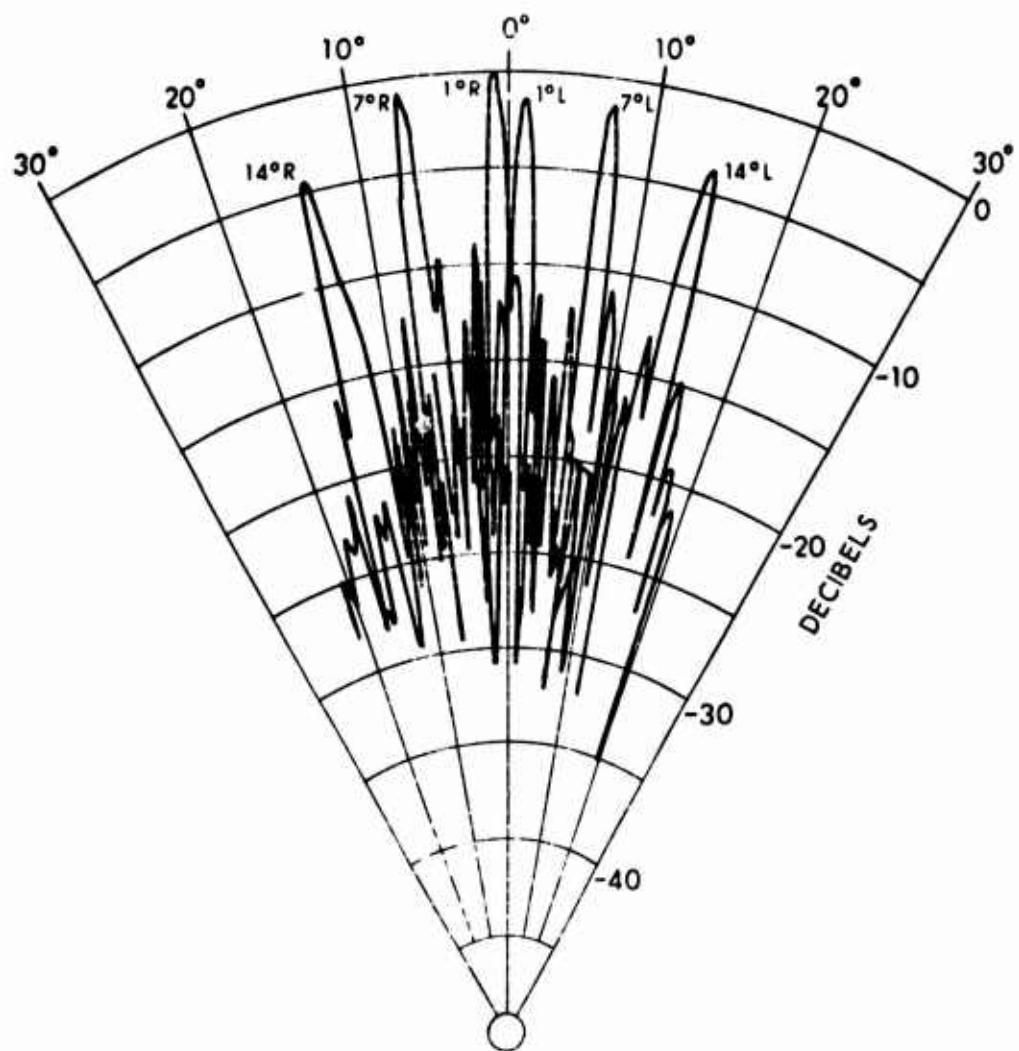


FIGURE 16
POLAR PLOT OF PRIMARY BEAMS
70.00 kHz
0 dB CORRESPONDS TO A SOURCE
LEVEL OF +220 dB re 1 μ Pa at 1 m

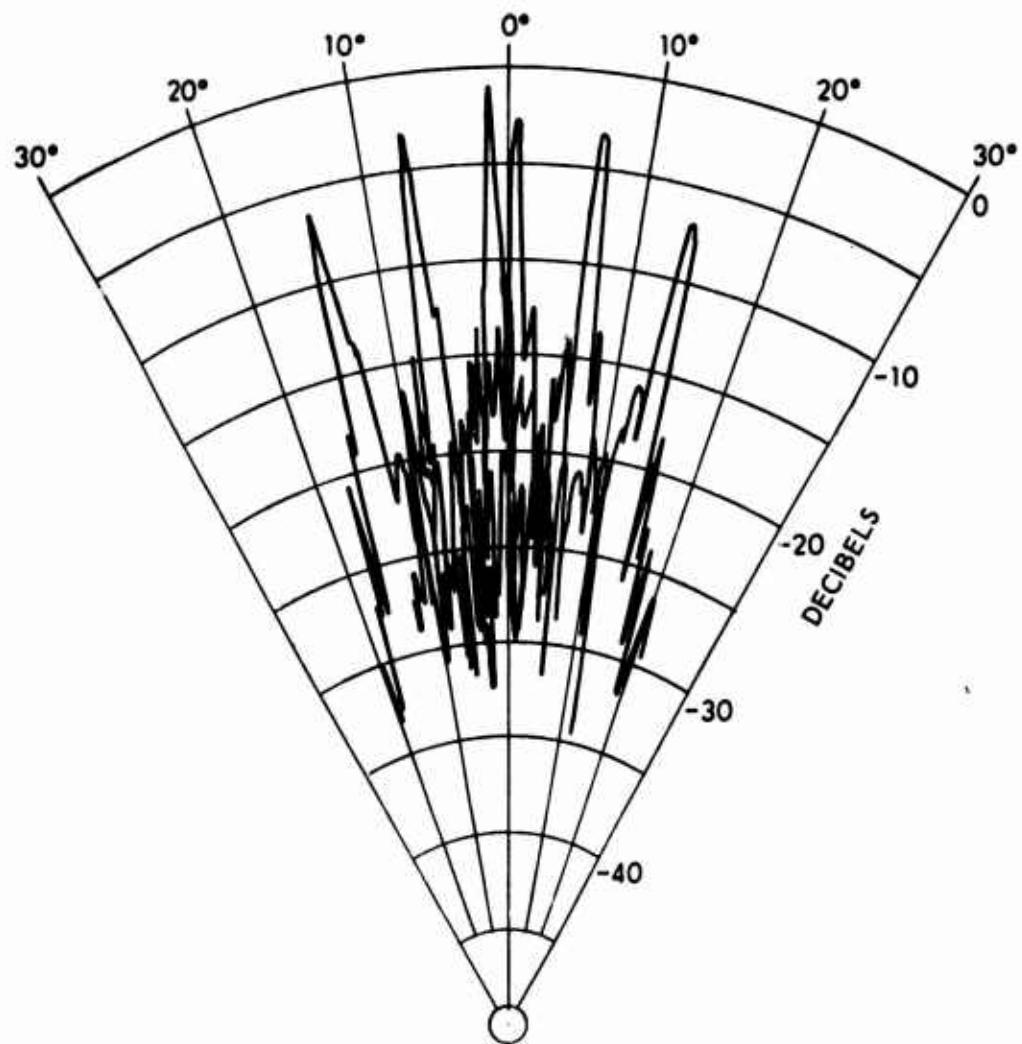


FIGURE 17
POLAR PLOT OF PRIMARY BEAMS
83.95 kHz
0 dB CORRESPONDS TO A SOURCE
LEVEL OF +220 dB re $1 \mu\text{Pa}$ at 1 m

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RLW - DR
12 - 19 - 73

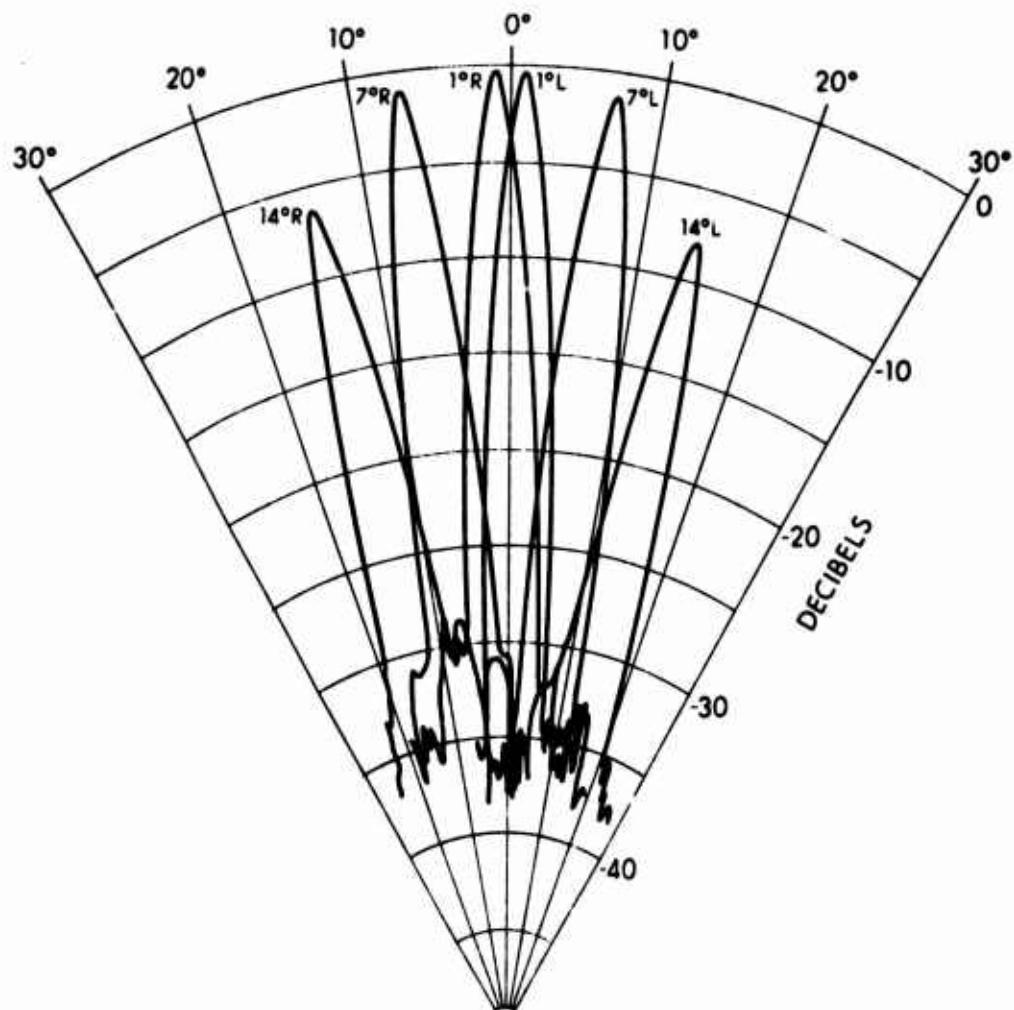


FIGURE 18
 POLAR PLOT OF DIFFERENCE FREQUENCY BEAMS
 13.95 kHz
 0 dB CCRRESPONDS TO A SOURCE
 LEVEL OF +181 dB re 1 μ Pa at 1 m

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 AS-73-1167
 RLW - DR
 11 - 13 - 73

however, resemble the projector beam pattern shown in Fig. 13 as closely as expected. This as yet unexplained dissimilarity between the pattern shapes reduces confidence in the measurement of the primary 3 dB beamwidths. An approximate comparison can, however, still be made. The measured 3 dB beamwidth of the 70.00 and 83.95 kHz primary beams was approximately 1° for all scan angles. The measured 3 dB beamwidth of the difference beams shown in Fig. 18 widened as the scan angle increased. This was an expected result. The parametric beam which was deflected 1° from the projector axis was 1.7° wide at its -3 dB points, whereas the beam at 14° deflection was 2.0° wide.

Comparisons of the source levels of the primary and parametric beams are also significant. These data were calculated from pressure measurements at a point on the projector axis, in the farfield of the projector. The source levels thus calculated were +219 and +220 dB re 1 μ Pa at 1 m for 83.95 and 70.00 kHz, respectively. The source level of the parametric beam was +181 dB re 1 μ Pa at 1 m.

V. CODED PULSE SCANNING SYSTEM: OPERATION

A. General Description

The coded pulse scanning system transmits a sequence of pulse words into predetermined scan sectors. Each pulse word, identified by the pulse carrier frequencies, is a sequence of one to four cw pulses. In the scan sequence, every sector has a unique word, as illustrated in Fig. 1. The system is capable of generating carrier frequencies at 8, 10, 12, and 14 kHz and of transmitting pulses at one of these frequencies in any preprogrammed order. The scan generator produces the primary frequencies required to obtain the difference frequencies; it also contains the panel on which the code sequence is programmed. The panel is used to select the number of sectors to be scanned, the number of pulses to be transmitted in one sector (word length), and the carrier frequency of each pulse in a given word. Figure A-3 in the appendix is a photograph of the code selection panel.

B. The Code Selection Panel

1. Panel Layout

The code selection panel is divided into three groups of jacks, labeled "code", "frequency", and "reset". (See Fig. A-3 in the appendix.) Each of these groups is further divided into columns labeled "P" (pulse) and "S" (sector). The frequency group has four groups of "P" and "S" columns marked F_1 , F_2 , F_3 , and F_4 , which represent the four obtainable carrier frequencies. Specifically, they are

F_1 - 8 kHz,
 F_2 - 10 kHz,
 F_3 - 12 kHz, and
 F_4 - 14 kHz.

2. Notation

The code selection panel is programmed by interconnecting the jacks in the three groups described above. A notation system which will be used in the following discussion to describe these interconnections is presented here. The notation is used to describe the location of a single jack on the code selection panel. This description requires the specification of the group, column, and row in which the jack is located; i.e., (code, S, 2) identifies the jack in the second row of column S of the code group. Notice that the notation is enclosed in parentheses.

3. Steps in Programming

a. Selection of the Number of Sectors

When the scan generator is programmed the number of sectors to be scanned is selected first. This selection is made by connecting (reset, S) to (code, S, n+1), where n is the number of sectors to be scanned. For example, if two sectors are to be scanned, then n=2 and (reset, S) is connected to (code, S, 3) with a patch cord. If n=4, no connection is made and reset is accomplished internally.

b. Selection of the Number of Pulses per Word

Following the selection of the number of scan sectors, the number of pulses per word is selected by patching from (reset, P) to (code, P, n+1). Again, if n=4, no connection is made and the generator resets internally at the end of each word.

c. Frequency Selection

Frequency selection is the last step in programming the scan generator. When the frequency F_k is selected for the l th pulse of

the m th sector, then (F_k, P, l) is patched to (code, P, l) and (F_k, S, m) is patched to (code, S, m) . For example, F_1 , is chosen to be transmitted in pulse 2 of the sector 3 code word. The steps in programming this selection are $(F_1, P, 2)$ to $(\text{code}, P, 2)$ and $(F_1, S, 3)$ to $(\text{code}, S, 3)$.

4. Carrier Level Adjustment

The level of the two carrier frequencies can be set separately by adjusting the trimmer potentiometers on board 6 of the scan generator. These potentiometers are shown in Figs. A-10 and A-11 of the appendix.

REFERENCES

1. D. H. Brown, "Applications of Information Theory to High Resolution Sonar Systems" (U), Mine Advisory Committee Report, Control No. 69-R:NRC:MAC:2027, National Research Council, Washington, D. C. (March 1969). SECRET
2. C. L. Bartberger, "Lecture Notes on Underwater Acoustics," Naval Air Development Center Report No. AD 468 869, Naval Air Development Center, Johnsville, Pennsylvania (17 May 1965).
3. H. O. Berkay, "Coded Signal Design for a Transmitter Scanned Sonar" (unpublished manuscript).

APPENDIX

This appendix contains photographs and schematic diagrams of those components of the coded pulse scanning system which are referenced in Sections III and IV.

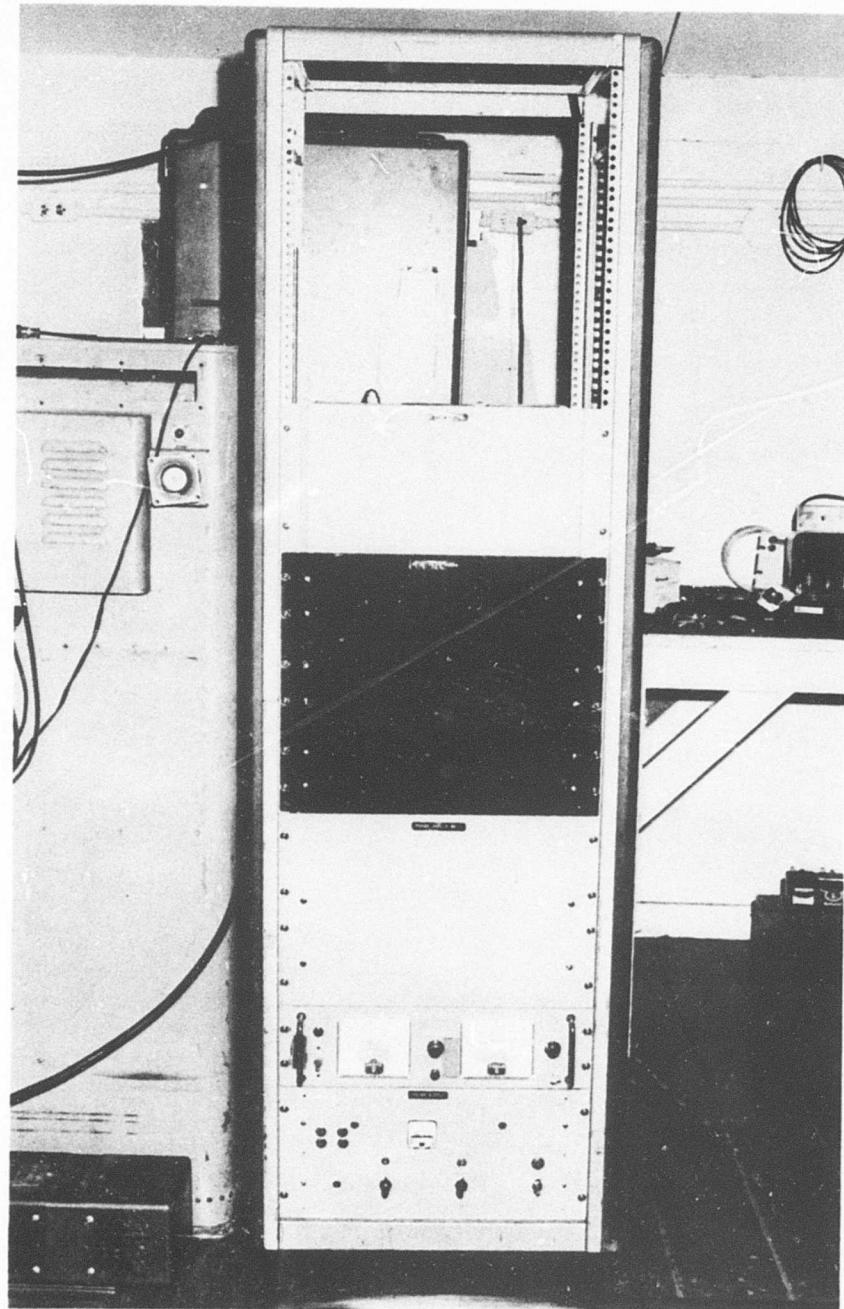


FIGURE A-1
CODED PULSE SCANNING SYSTEM WITHOUT
SCAN GENERATOR (FRONT VIEW)

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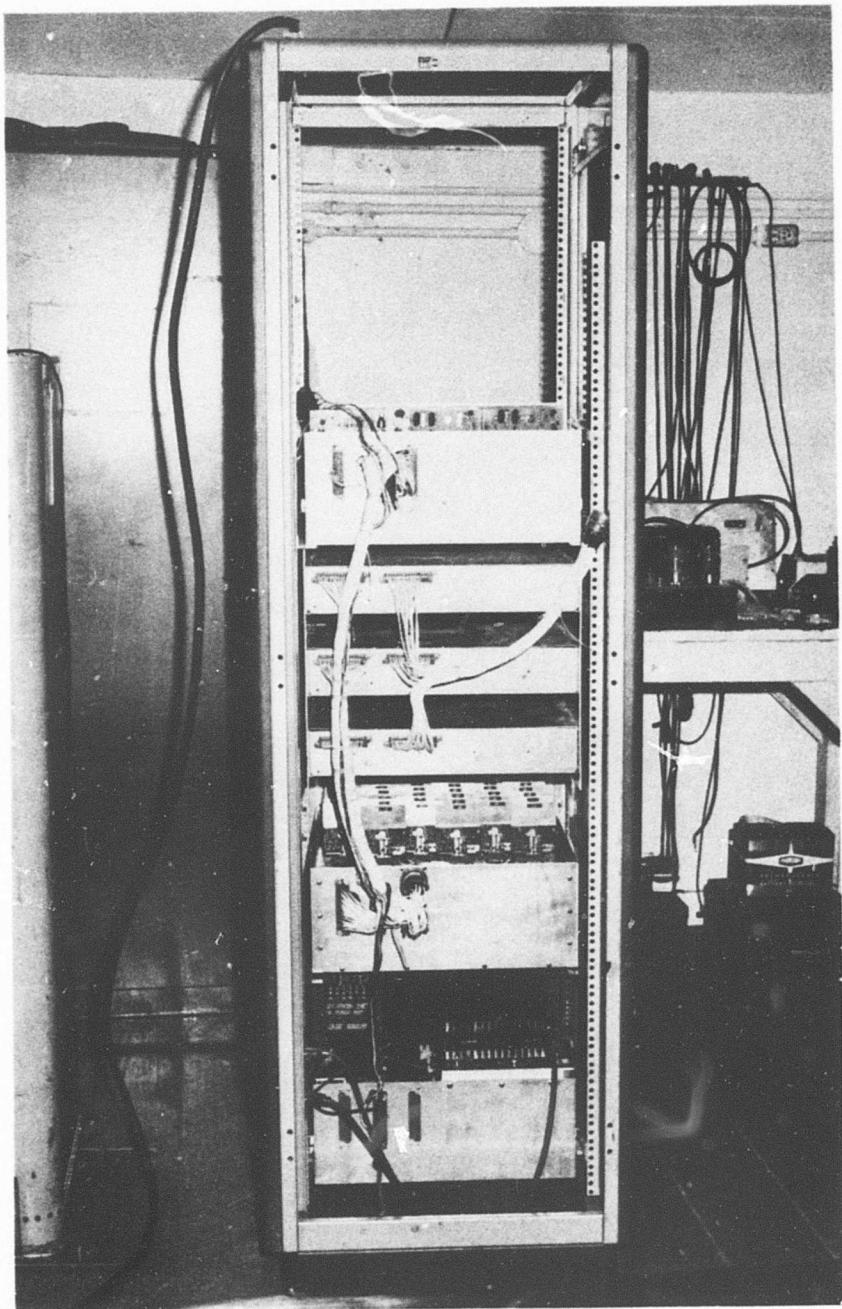


FIGURE A-2
CODED PULSE SCANNING SYSTEM WITHOUT
SCAN GENERATOR (REAR VIEW)

0166(08)-5

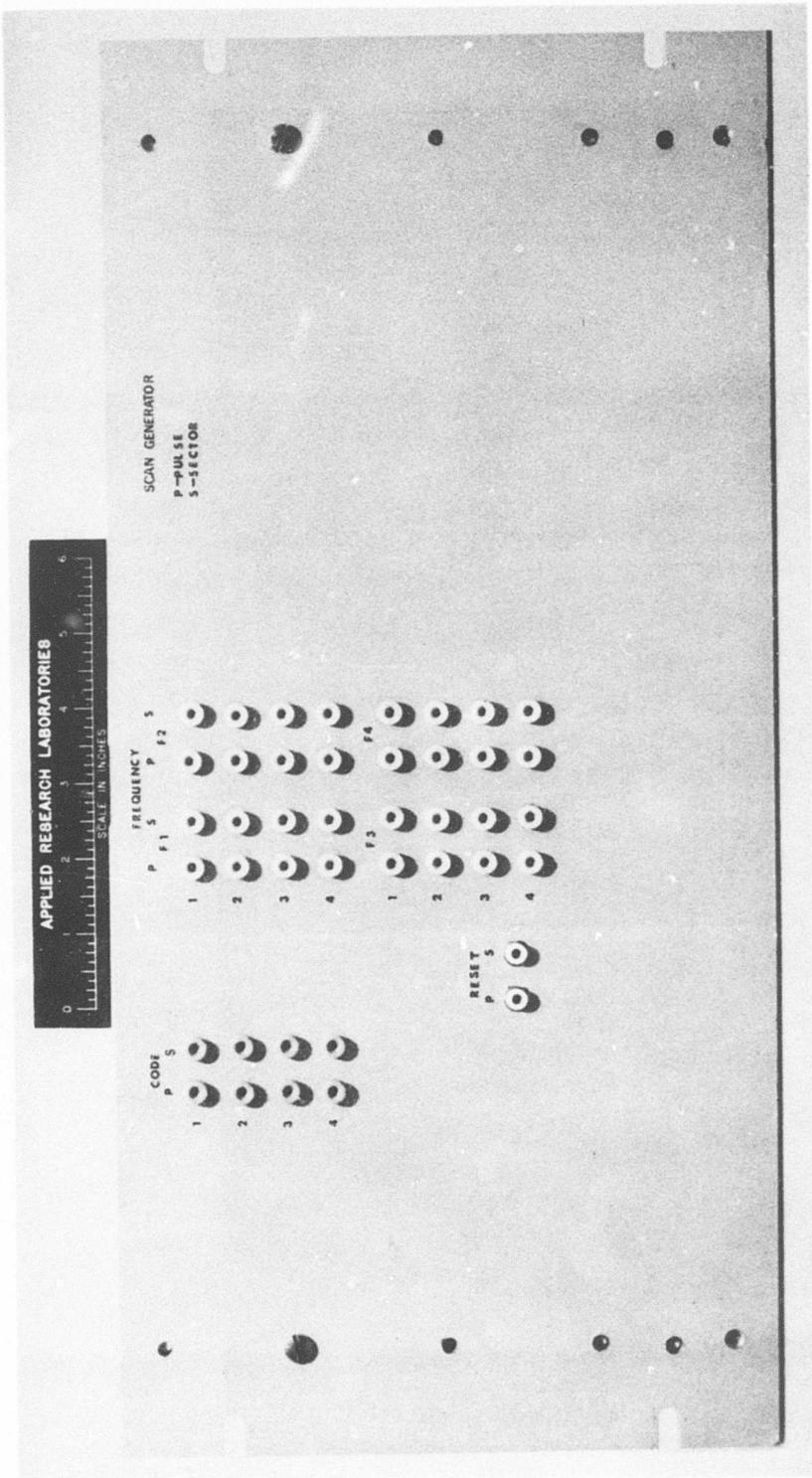


FIGURE A-3
FRONT PANEL SCAN GENERATOR

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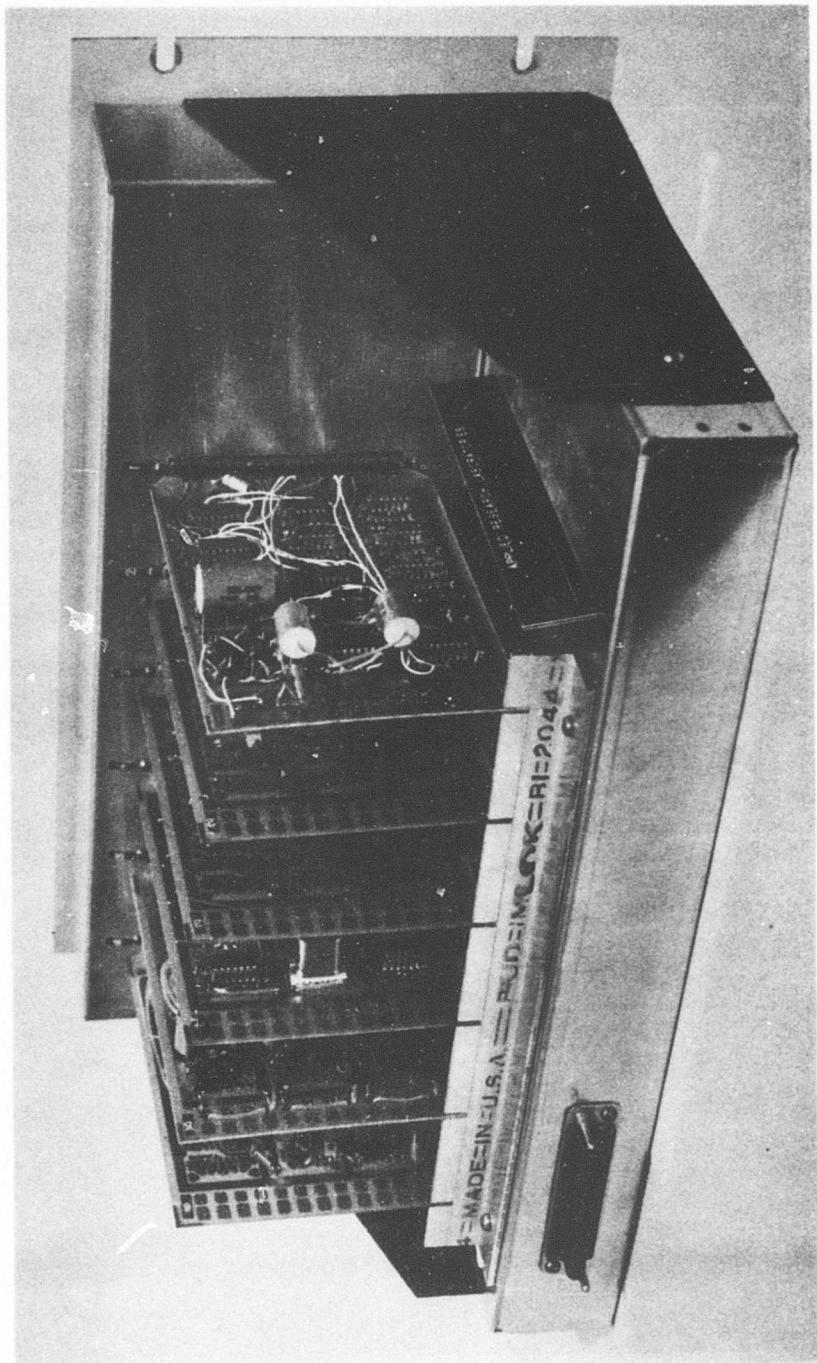


FIGURE A-4
SCAN GENERATOR (REAR VIEW)

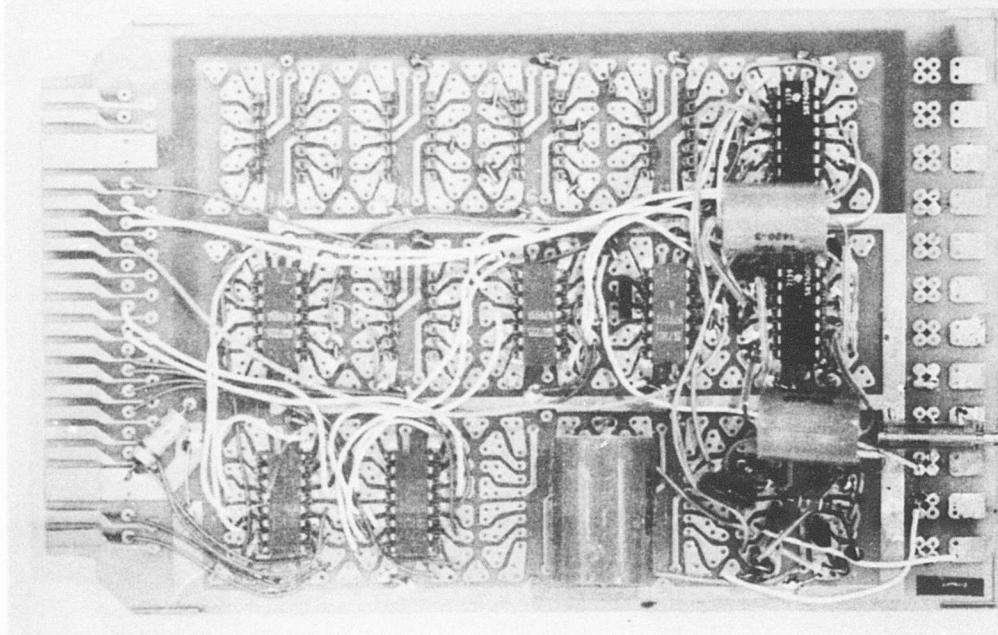


FIGURE A-5
OSCILLATOR BOARD, SCAN GENERATOR
(LEFT SIDE)

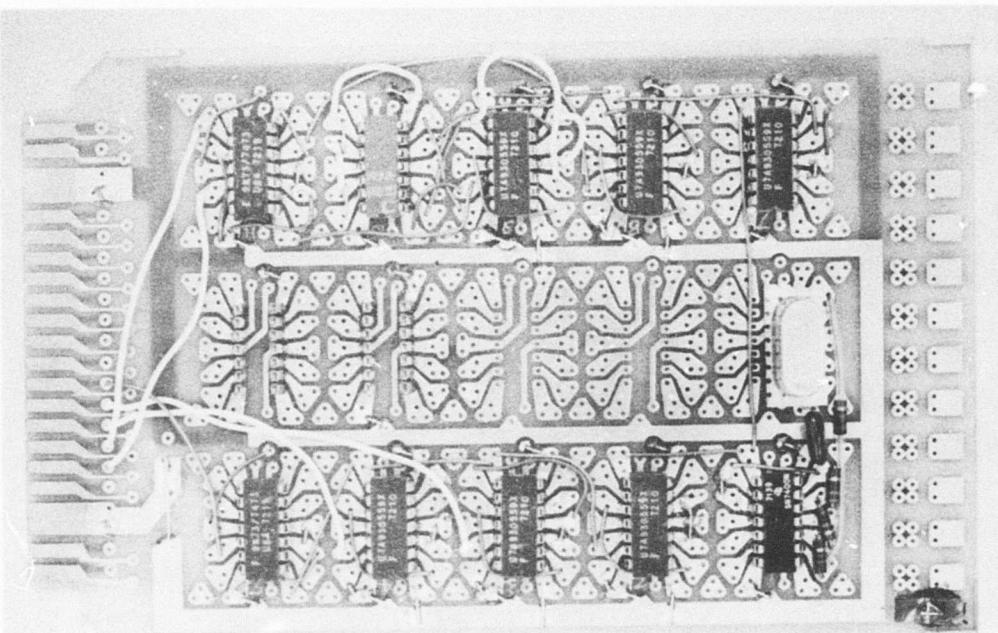


FIGURE A-6
CODE GENERATOR, SCAN GENERATOR
(RIGHT SIDE)

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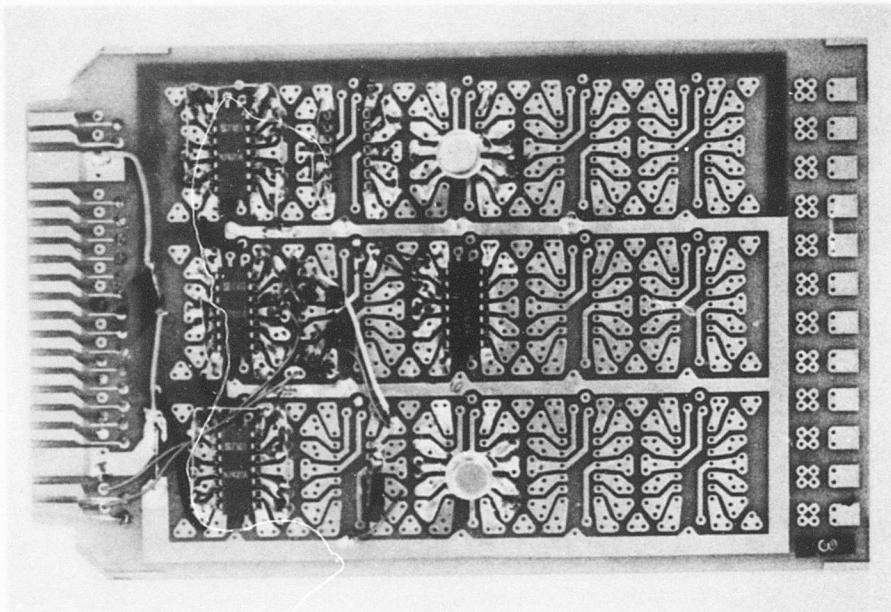


FIGURE A-7
DECODER AND SECTOR SELECTOR
SCAN GENERATOR

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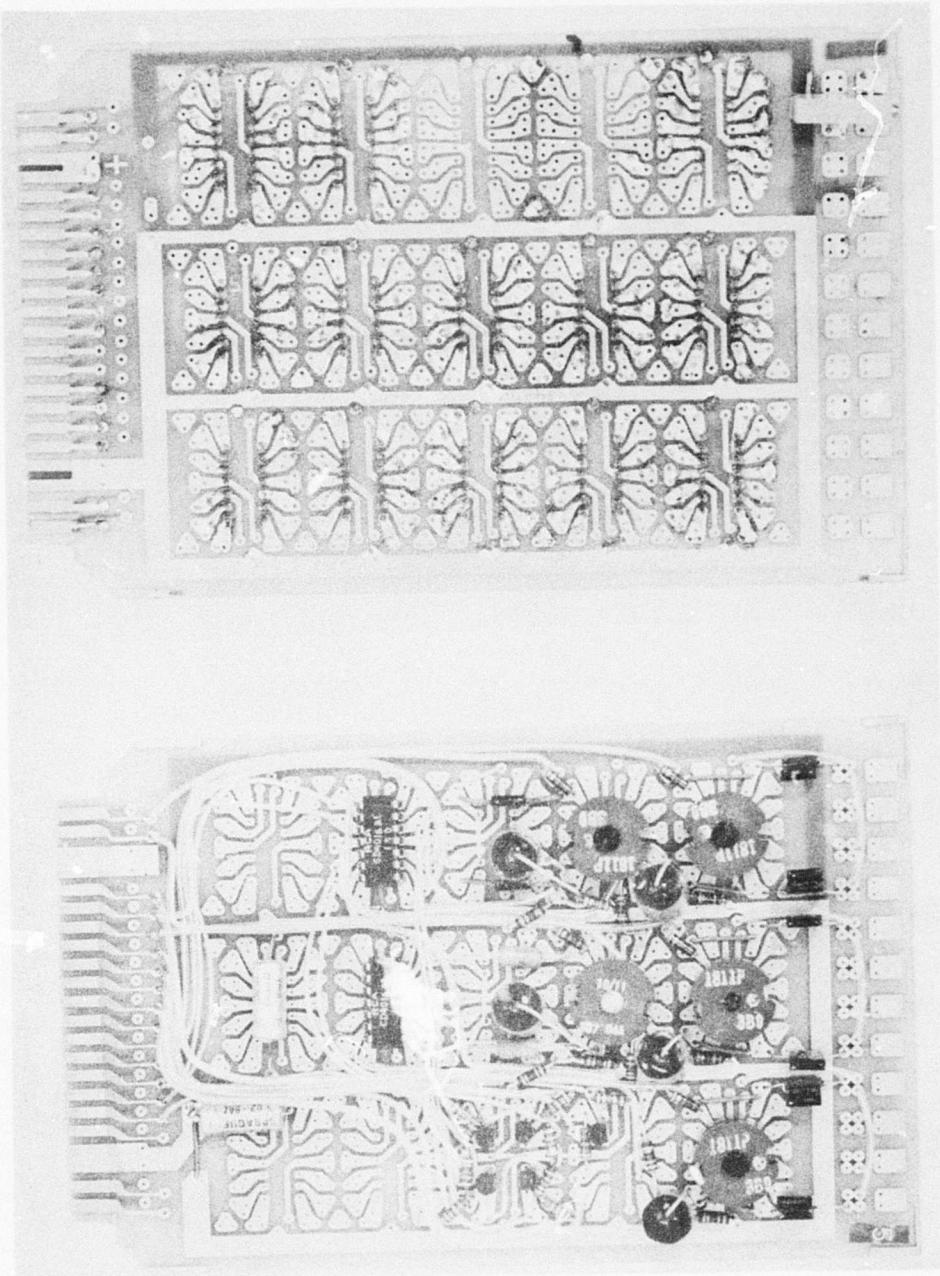


FIGURE A-8
LOW PASS FILTER AND FREQUENCY
SELECTOR BOARD (BOTTOM VIEW)
(LEFT SIDE)

FIGURE A-9
LOW PASS FILTER AND FREQUENCY
SELECTOR BOARD (TOP VIEW)
(RIGHT SIDE)

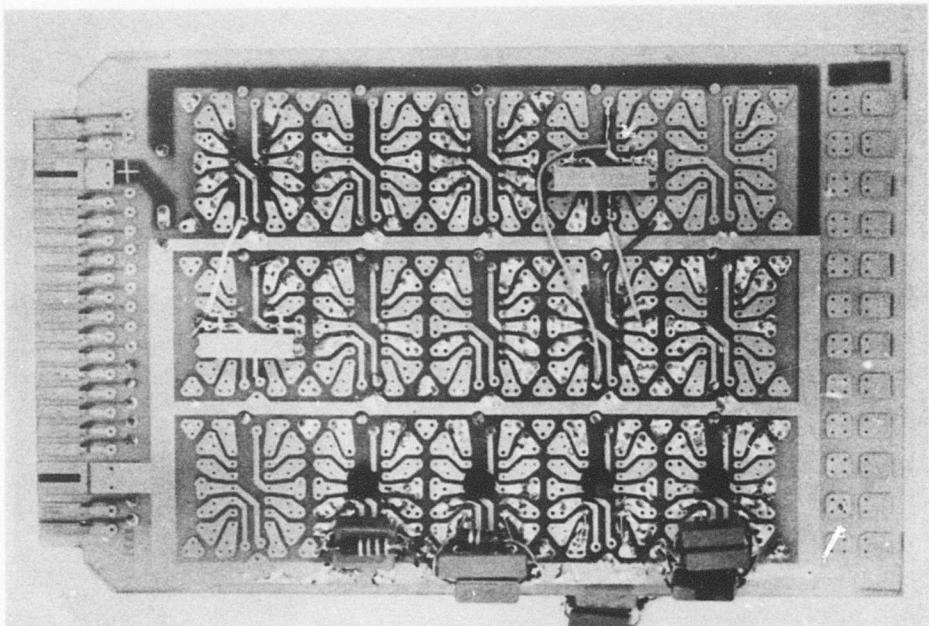


FIGURE A-11
MIXER BOARD (TOP VIEW)

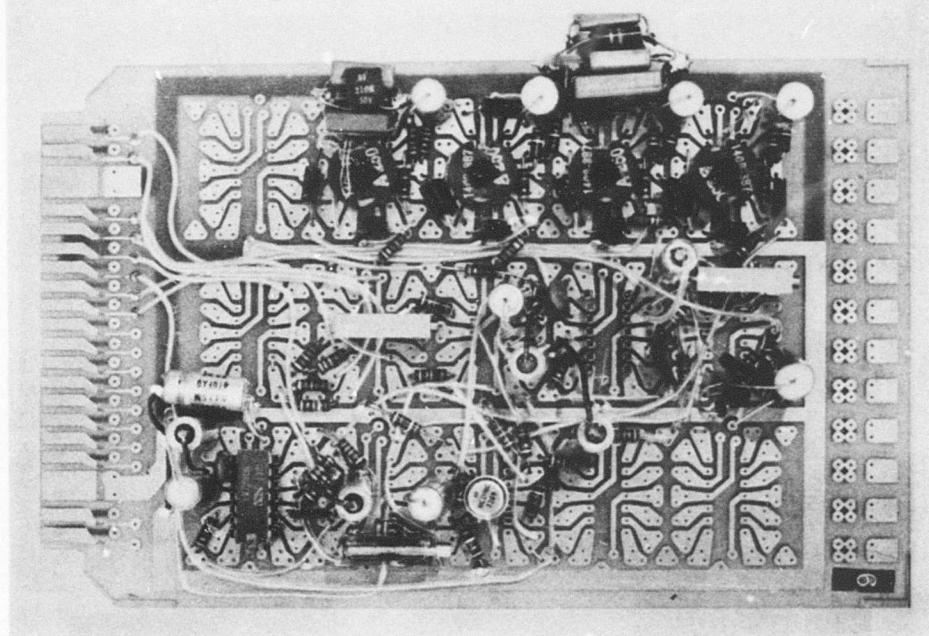


FIGURE A-10
MIXER BOARD (BOTTOM VIEW)

0166(08)-11

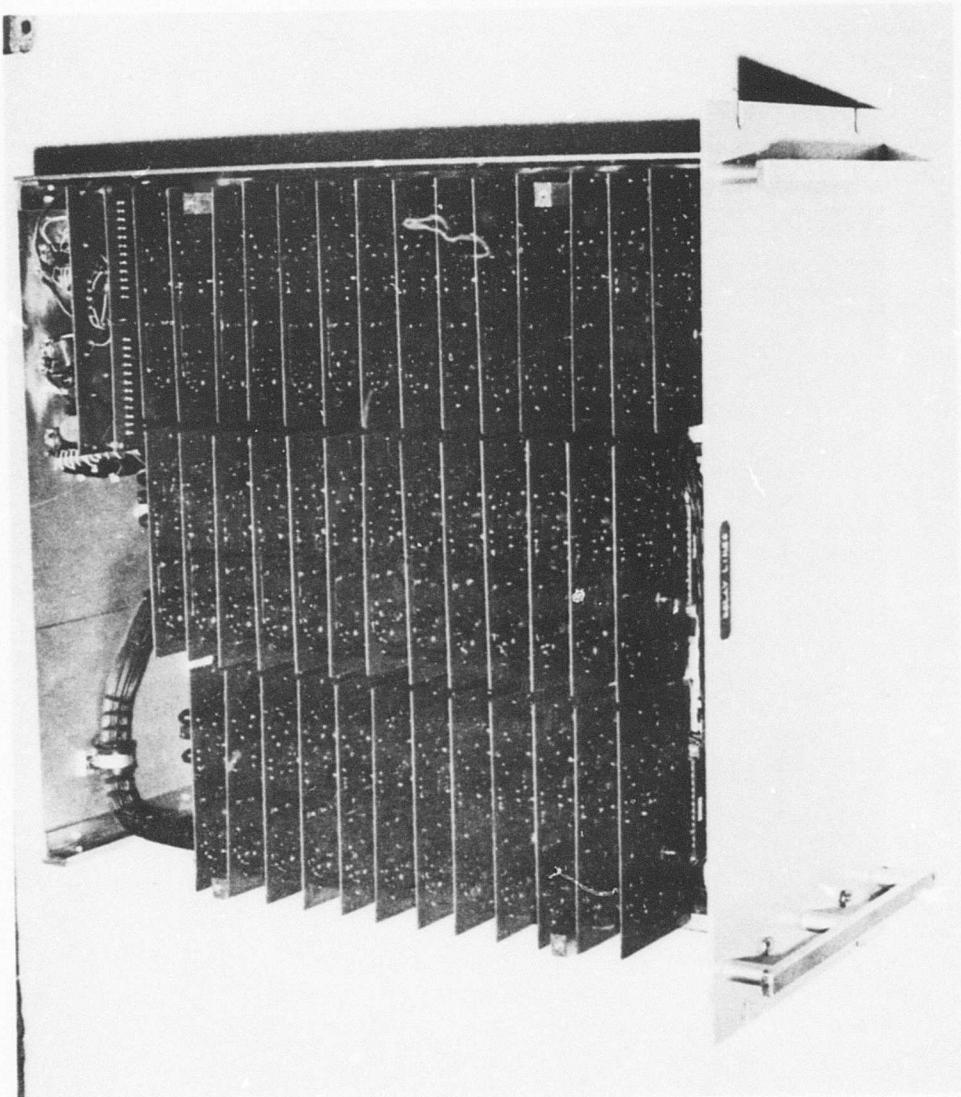


FIGURE A-12
DELAY LINE CHASSIS SHOWING PA DRIVERS (TOP VIEW)

0166(08)-12

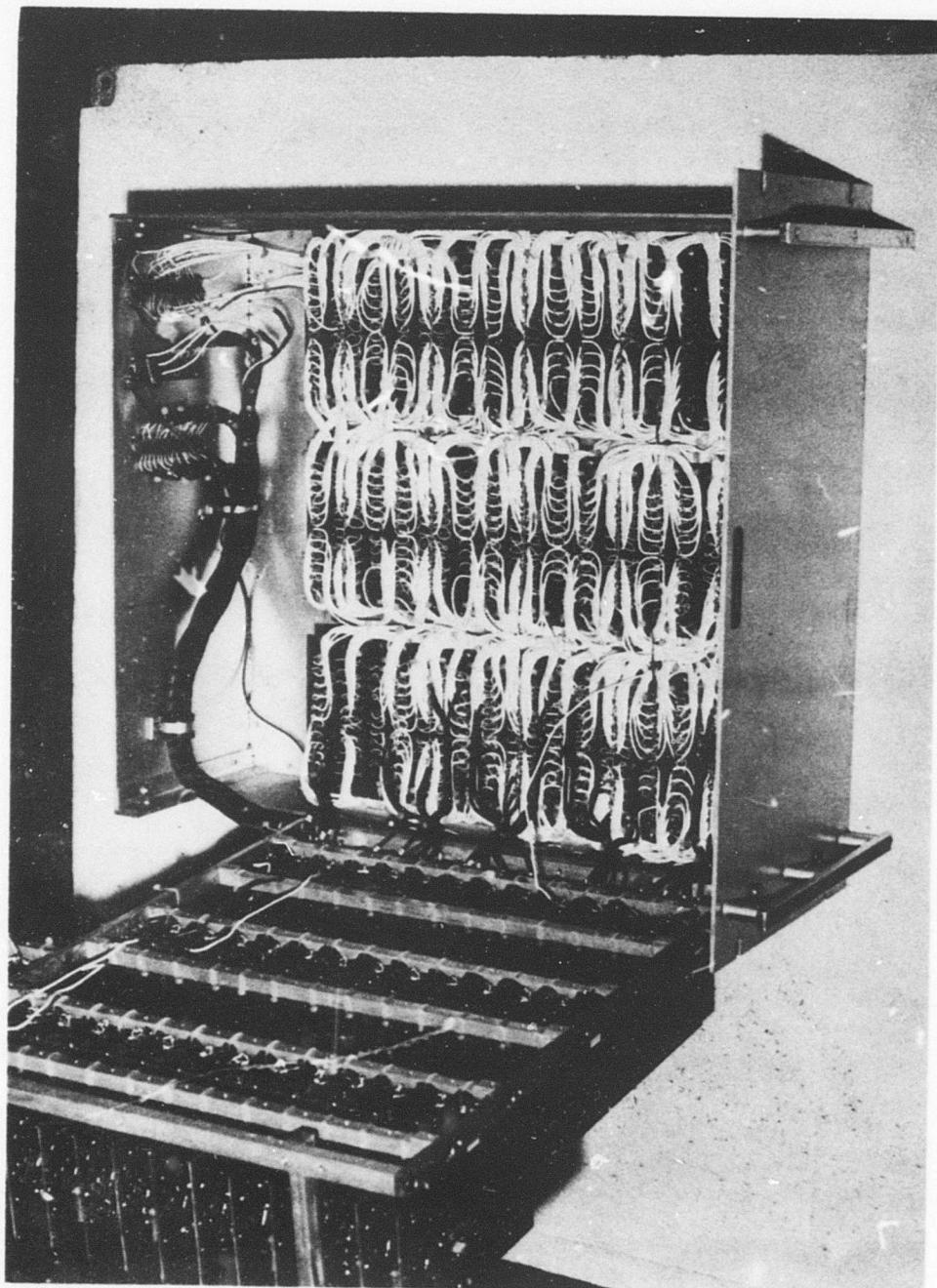


FIGURE A-13
DELAY LINE CHASSIS SHOWING DELAY LINES (TOP VIEW)

0166(08)-13

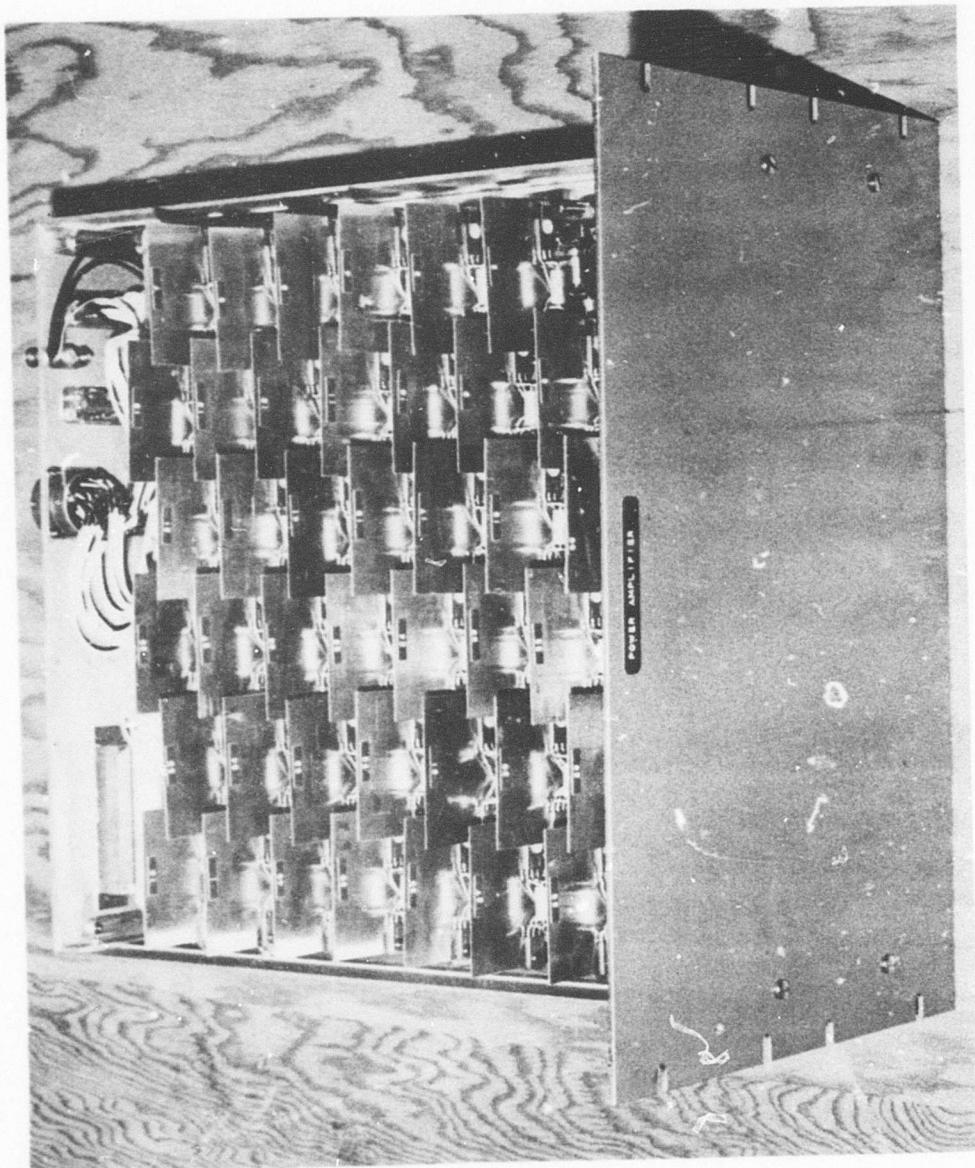


FIGURE A-14
POWER AMPLIFIER (TOP VIEW)

0166(08)-14

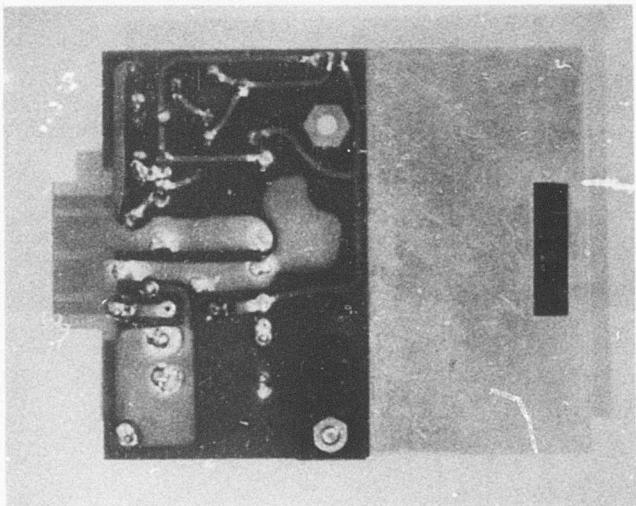


FIGURE A-16
POWER AMPLIFIER MODULE (TOP VIEW)
(RIGHT SIDE)

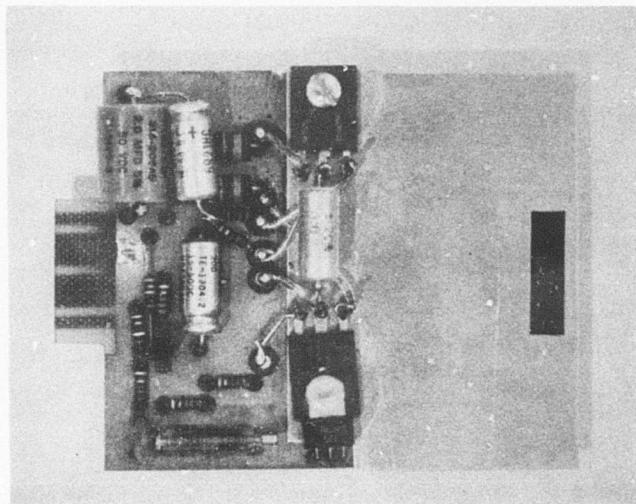


FIGURE A-15
POWER AMPLIFIER MODULE (BOTTOM VIEW)
(LEFT SIDE)

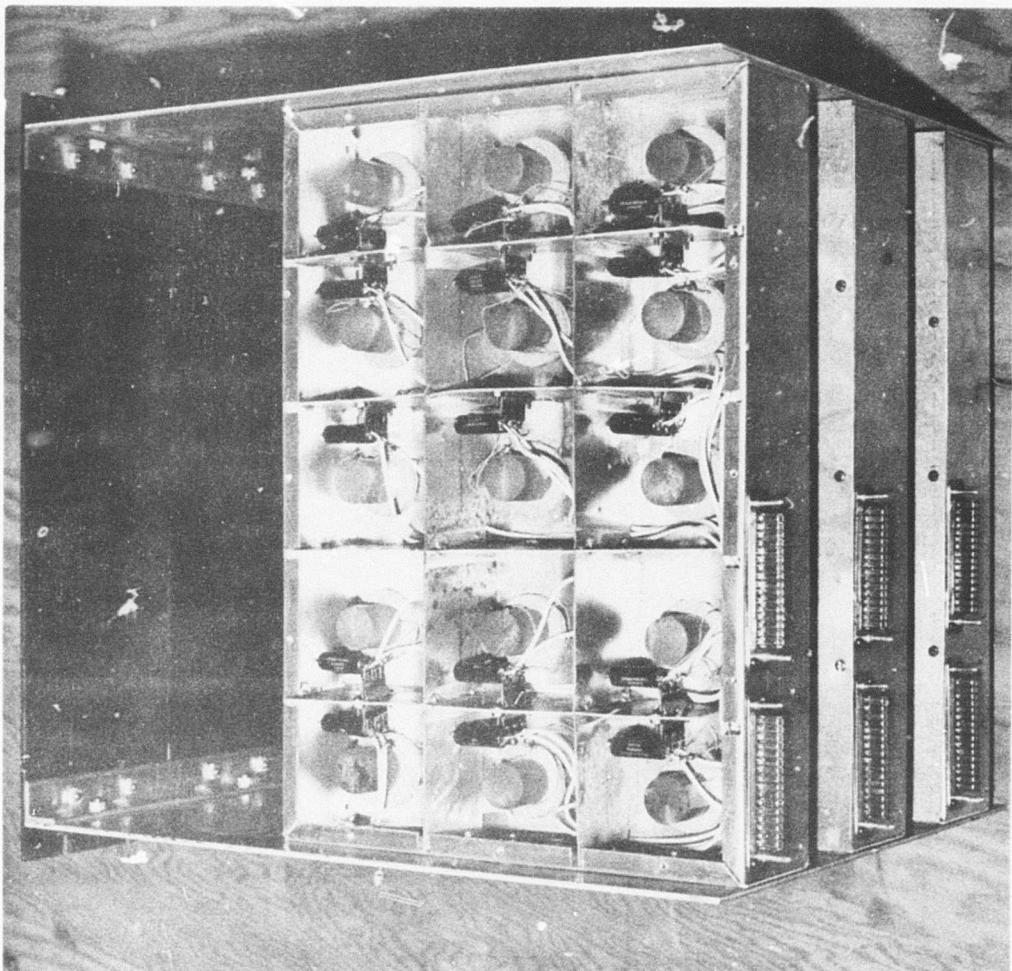


FIGURE A-17
MATCHING NETWORKS (TOP VIEW)

0166(08)-16

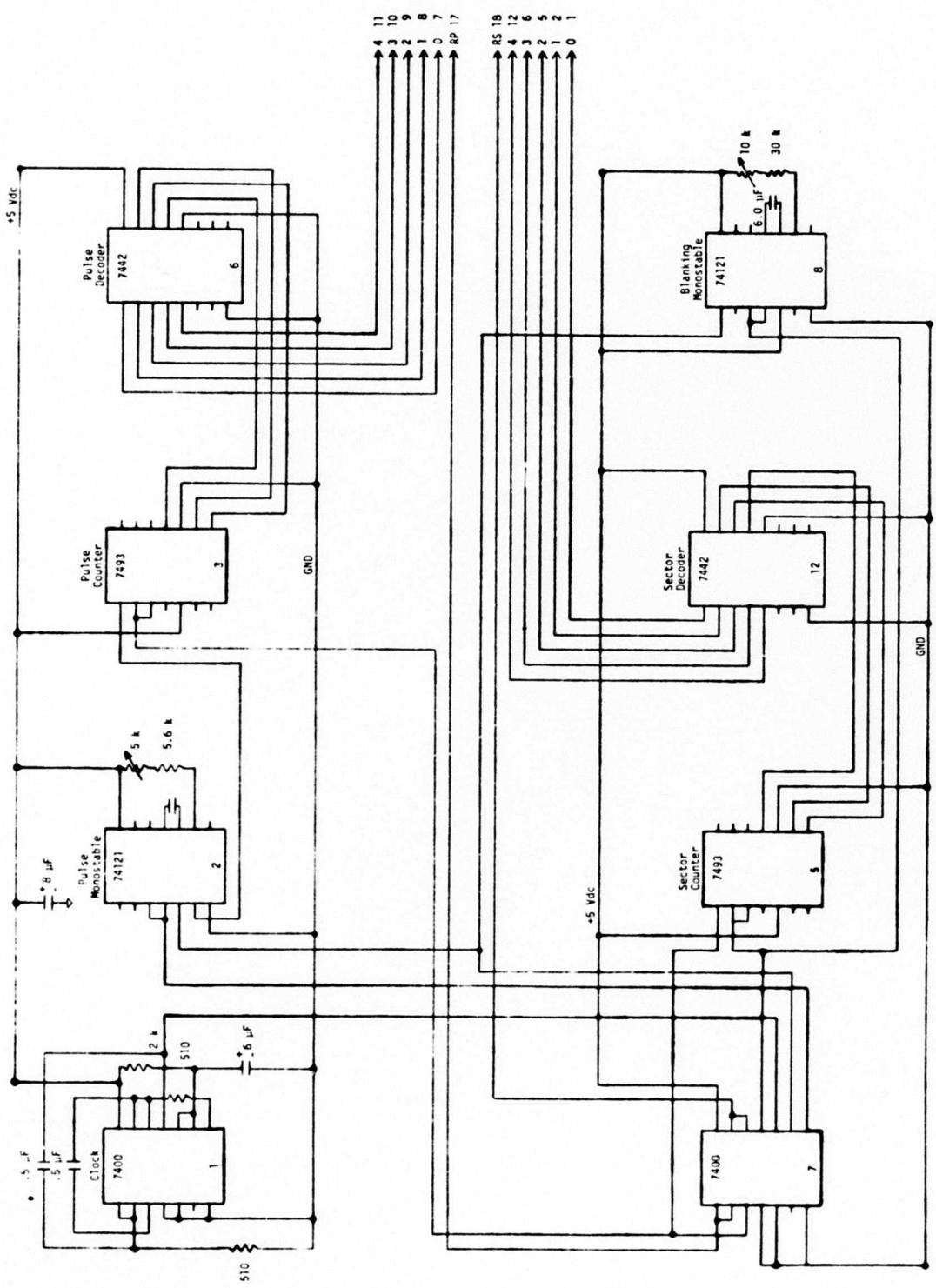


FIGURE A.18
SCHEMATIC DIAGRAM, SCAN GENERATOR, CODED PULSE TRANSMITTER

CS-73-1862
RLW-0166-8

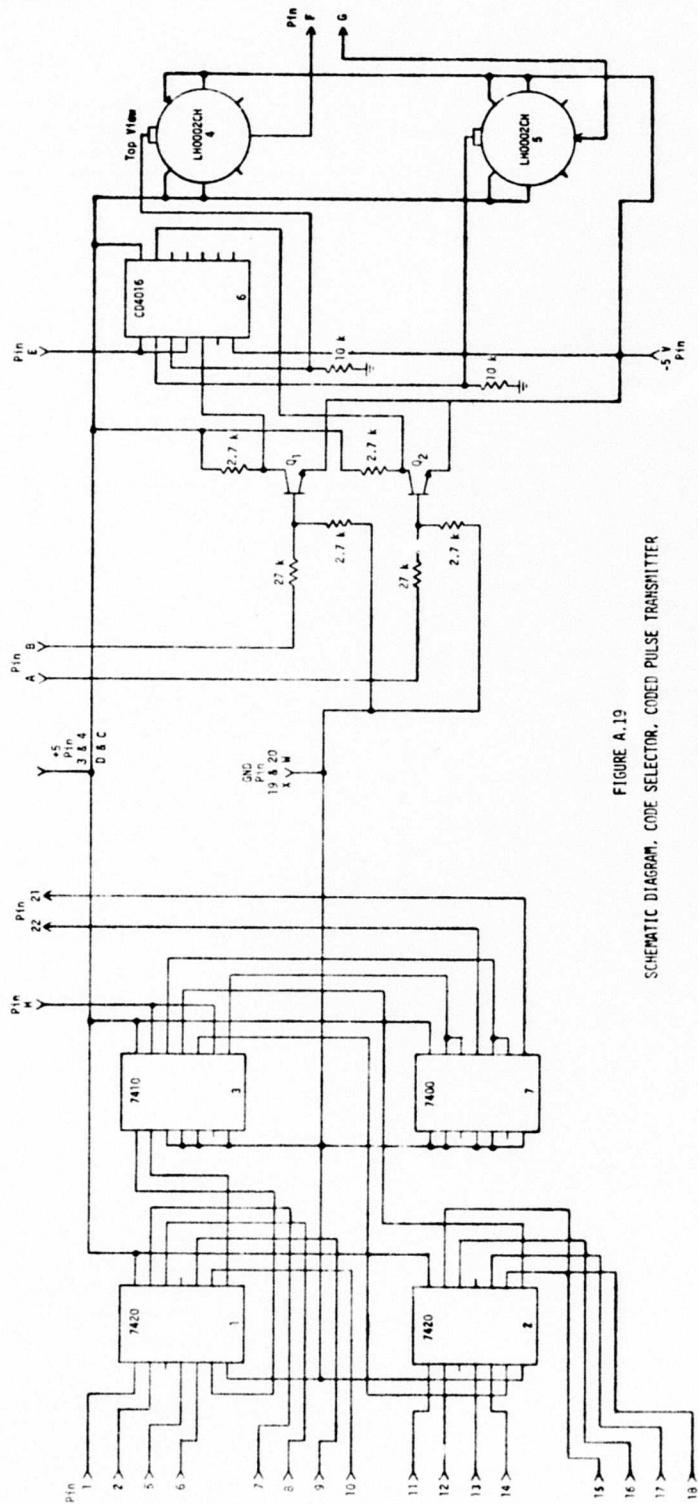


FIGURE A.19
SCHEMATIC DIAGRAM, CODE SELECTOR, CODED PULSE TRANSMITTER

CS-73-1863
BLW-0156-8

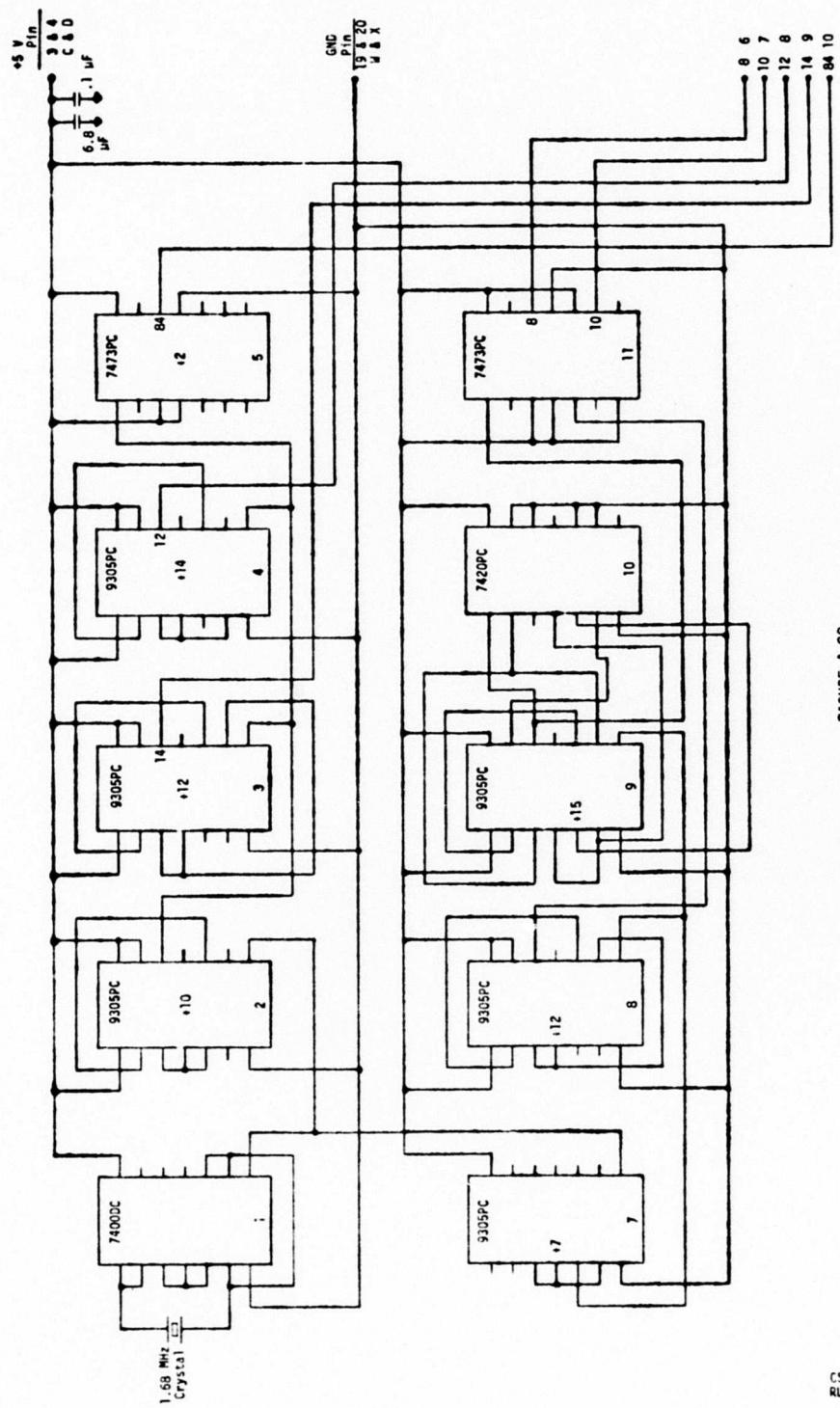


FIGURE A.16
SCHEMATIC DIAGRAM, OSCILLATOR CODED PULSE TRANSMITTER

CS-73-1854
RLW-0166-8

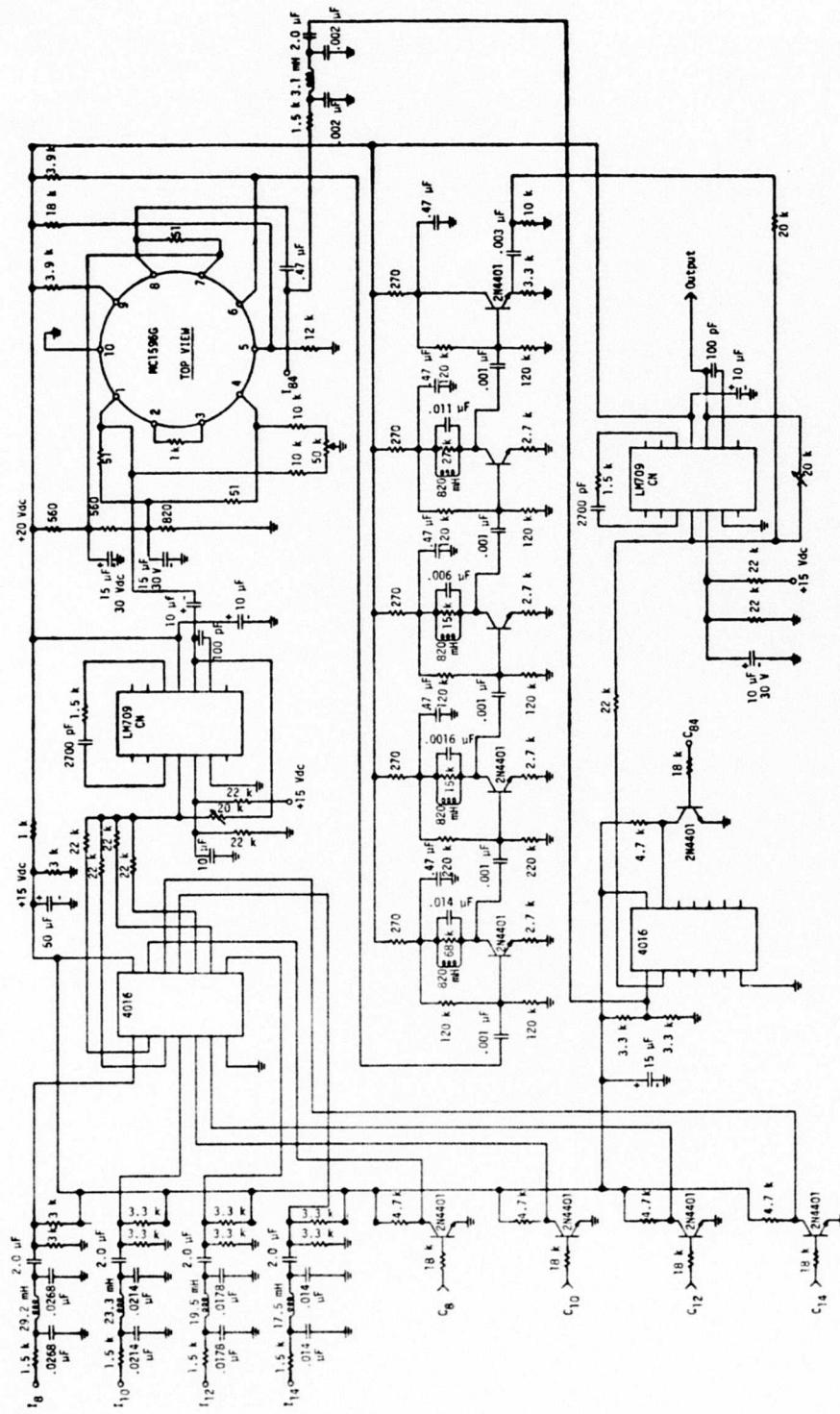


FIGURE A.21
SCHEMATIC DIAGRAM, FILTER SUMMER BOARD, CODED PULSE TRANSMITTER

CS-73-1917
RM-0166-8

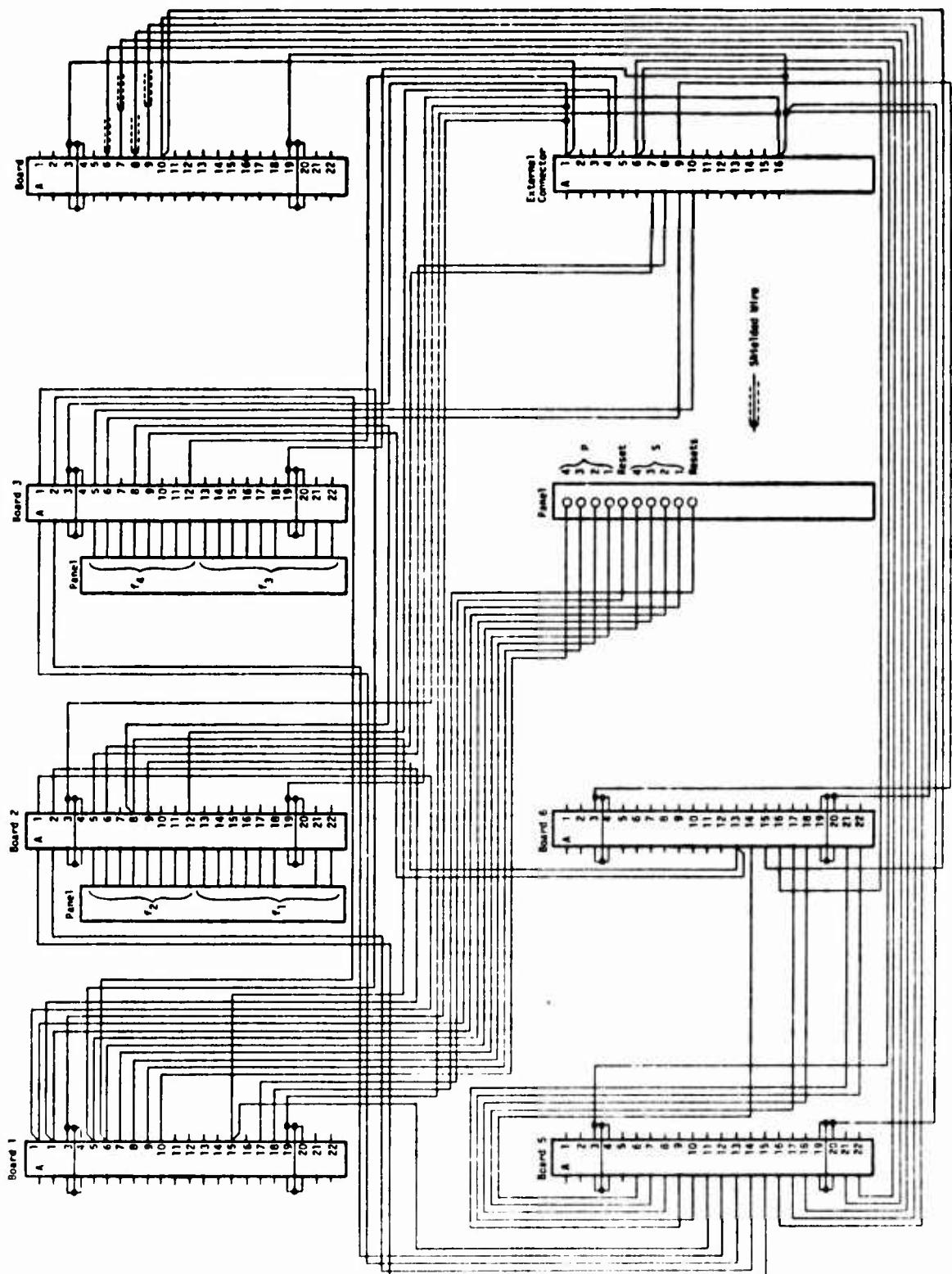


FIGURE A.22
INTERCONNECTION DRAWING, SCAN GENERATOR, CODED PULSE TRANSMITTER

11-73-1447
PLW-C166-2

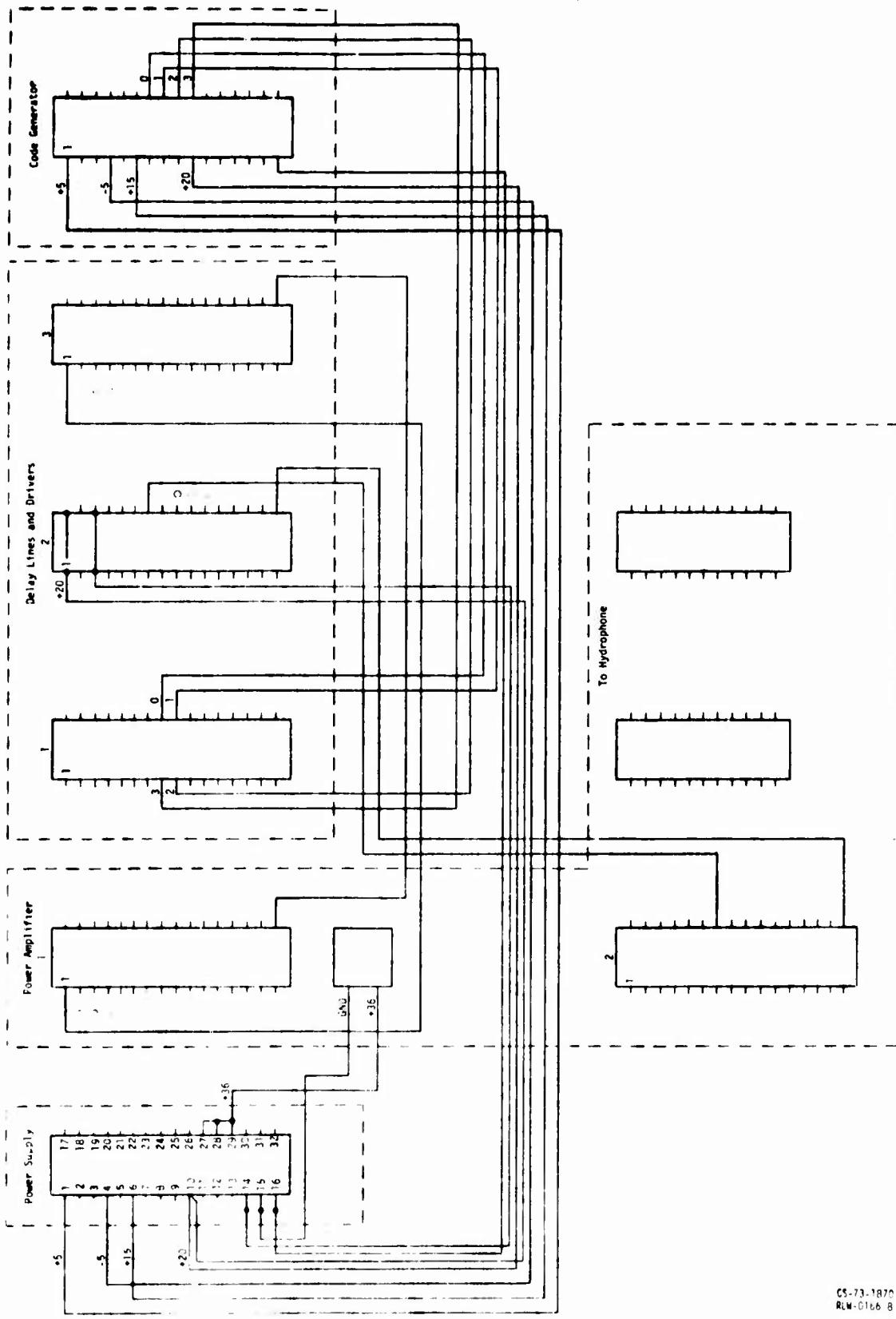


FIGURE A.23
INTERCONNECTION DRAWING, COMPLETE SYSTEM, CODED PULSE TRANSMITTER

CS-73-1870
RLW-0166 8